

# THE INTERNATIONAL JOURNAL OF SCIENCE & TECHNOLEDGE

## Inoculating *Artemia Nauplii* for the Purification of Brine and Enhancement of Quantity and Quality of Sodium Chloride in the Solar Saltpans of Kanyakumari

**Dr. G. Leema Rose**

Associate Professor, Department of Chemistry, Holy Cross College, Tamil Nadu, India

### **Abstract:**

An investigation was made on the inoculation of brine shrimp *Artemia nauplii* in the evaporation ponds such as primary, secondary, tertiary condensers and crystallizers of two solar saltpans (SP1 and SP2) which use sea and estuarine water respectively for solar salt production for one year in four different seasons. Season I, (May, June and July), season II (August, September and October), and season IV (February, March and April). The third season (November, December and January) failed to have salt samples due to the northeast monsoon. The evaporation rate of the brine, the quality parameters of the salt, the amount of salt harvested and the heavy metal content of the salt samples of both the control and the experimental ponds were determined. The evaporation rate was found to be greater in the *Artemia* inoculated ponds than in the control ponds and the maximum percentage difference of evaporation rate observed was 20%. Among the various salt quality parameters analysed, moisture content, insoluble impurities, calcium sulphate, magnesium sulphate and magnesium chloride contents decreased from the control to the experimental samples and the sodium chloride content increased by 3 to 4%. There was an increase in the amount of sodium chloride harvested and the percentage difference between the control and the experimental samples was 15 to 16%. Heavy metals like chromium, lead, iron, cobalt, manganese and zinc contents of the salt decreased from the control to the experimental samples. The seasonal variation of the different parameters observed was higher in the case of post monsoon II (season IV) than in the other two seasons.

**Keywords:** Saltpans, *Artemia nauplii*, salt quality parameters, sodium chloride, heavy metals etc.

### **1. Introduction**

Solar salt works are well known chemical plants mainly because of their product called sodium chloride (J. C. Hocquet and J.Hocquet, 1987). It is the first chemical; next to water to have attracted human attention (G.Young, 1977) .It is one among the top five essentials of life. Sodium chloride forms the bed rock for many chemical industries and is the source for sodium and chlorine two of the twelve dominant elements in the human body. Apart from its use as an edible commodity, it finds more than 14,000 commercial applications. Common salt is distributed in nature as rock salt (halite) and brine. Evaporation of brine using solar power in solar saltpans leads to solar salt. Rock salt and solar salt contribute equally to world's annual salt production. To produce solar salt sea or estuarine brine is concentrated in a series of ponds called reservoirs, condensers and crystallizers using solar power. As evaporation proceeds the salinity of brine gradually increases from 3 to 24° Be, where sodium chloride starts to crystallize. At low salinity levels salts like, calcium carbonate and gypsum crystallize, where as at salinities beyond 27° Be salts of magnesium begin to crystallize. Thus, production of solar salt involves the selective recovery of sodium chloride, a process based on varying solubility. More than 100 countries have the access for solar salt cultivation and more than 100 million metric tonnes of salt has been manufactured through solar evaporation. Though evaporation of brine leads to solar salt, the biological management of the ponds greatly decides the quality of the salt.

The small crustacean *Artemia*, also called brine shrimp often referred as clearer worm is the key organism involved in the biological process that takes place in solar salt works. The active brine shrimp population ingests and oxidizes much of the plankton and organic particulates in brine, releases waste products in faecal pellets, decreases the organic content of the water and clears the brine (Davis, 1978).Finally, it creates and maintains appropriate conditions in the evaporation ponds and crystallizers, for the continuous and the maximum production of high quality salt, which is characterized by clear, compact and thick granules (W.Tackaert and P. Sorgeloos,1993). Of the several procedures available to improve the quality and the quantity of salt produced, the important is the creation of conditions, conducive to large *Artemia* population and the use of crystallizers only for the deposition of salt (J. S. Davis and M. Giordano, 1996).

In the salt pans of Kanyakumari District, Tamilnadu, South India, the recruitment of *Artemia*, the key organism involved in enhancing the quality and the quantity of salt is not witnessed in all the salt works and is not continuous due to dilution by heavy rainfall during the monsoon seasons. Also, though *Artemia* is said to improve the salt quality in solar salt works, enough data in the literature is not available regarding the same. Hence the present study was undertaken as a preliminary work for a period of one year during the four seasons. (season I, season II, season III and season IV) to confirm that the small crustacean *Artemia* can be employed in solar salt works to enhance the quality and the quantity of salt.

## 2. Materials and Methods

Two salt works (SP1 and SP2) which use sea water and estuarine water independently for salt production were chosen for the present study. These salt works are located around the famous Manakudy lake which is five kilometers away from Kanyakumari the southernmost tip of India. In each salt work, four ponds each such as primary, secondary, tertiary condensers and crystallizers were selected and modified for *Artemia* inoculation. The area of the condenser and the crystallizer ponds were 600 and 200 m<sup>2</sup> with the depth of 35 and 15 cm respectively. The height of water in the ponds was maintained at 30 and 12 cm respectively. In addition to the experimental ponds, control ponds in triplicates were also maintained.

*Artemia franciscana* cysts imported from USA were allowed to hatch in sea water at a salinity of 3‰ in the laboratory and at second stage the nauplii were fed using rice bran extract and the salinity was raised to 8‰ gradually, which was then introduced into the experimental primary condensers of almost same salinity. The control ponds were maintained without the introduction of *Artemia*. After seven days, water was let into the secondary condensers when the salinity rose to 12 to 13‰. After staying in the secondary condenser for another five days, water was made to enter into the tertiary condensers. In the tertiary condenser, water was retained for four to six days where the salinity crossed 20‰. By that time the *Artemia* had attained the adult stage. The adult *Artemia* was not allowed to enter into the crystallizer pond, but the concentrated brine solution was let into the crystallizers. Sodium chloride crystallized within five days and was scraped, after one or two days. The process continued thereafter.

Salt samples harvested from the control and the experimental ponds were collected and weighed weekly and then summed for monthly. Salt samples for analysis were collected monthly from the two salt works and packed in air tight polythene containers for salt quality analysis. Evaporation rate was calculated monthly in the condensers (primary, secondary and tertiary) and crystallizers of both the experimental and the control ponds of the two salt works in the field itself. The different salt quality parameters like moisture content, insoluble impurities, calcium sulphate, magnesium sulphate, magnesium chloride and sodium chloride content, salt production (quantity) both in the control and the experimental salt samples were estimated using standard procedures (Vogel, 1969). Finally heavy metals like chromium, lead, manganese, zinc, copper, iron, cobalt and nickel were estimated using Atomic Absorption Spectrophotometer. The monthly values obtained in each case were segregated for season I, (May, June and July), season II (August, September and October), and season IV (February, March and April). The third season (November, December and January) failed to have salt samples due to the northeast monsoon.

### 2.1. Estimation of Chloride, Sulphate, Calcium, Magnesium, Sodium and Potassium

The chloride, sulphate, magnesium, calcium, sodium and potassium content of the various salt samples were determined as per standard procedures and calculations were done for salt quality parameters like calcium sulphate, magnesium chloride, magnesium sulphate sodium sulphate, sodium chloride, moisture content and insoluble impurities were determined as per salt department guidelines.

## 3. Results

### 3.1. Rate of Evaporation

The rate of evaporation and the percentage difference calculated in the control and the experimental ponds (primary, secondary, tertiary condensers and crystallizers) of the two salt pans (SP1 and SP2) during the three seasons is presented in Table 1 and 2 respectively.

The evaporation rate decreased from the primary to the tertiary condensers in both the salt works and then increased in the crystallizers. In the primary condensers of SP1 (sea water source) the maximum percentage difference observed between the control and the experimental ponds was  $6.7 \pm 0.23$  % in season II. Similarly in the secondary condensers the maximum percentage variation monitored between the control and the experimental ponds was  $8.8 \pm 0.42$  % in season IV. Likewise, the maximum difference in evaporation between the control and the experimental ponds witnessed in the tertiary condensers was  $6.8 \pm 0.4$  % during season II. In the case of crystallizers the maximum percentage difference in evaporation observed was  $19.8 \pm 1.3$  % in season IV.

In SP2 (estuarine water source) the maximum percentage difference in evaporation observed between the control and the experimental ponds was  $6.8 \pm 0.29$  % in season IV. Similarly, in the secondary condensers the maximum percentage variation monitored between the control and the experimental ponds was  $7.4 \pm 0.24$  % in season III. Likewise the maximum difference in evaporation witnessed in the tertiary condensers is  $9.7 \pm 0.36$  % during season II. In the case of crystallizers the maximum difference in evaporation observed between the experimental and the control ponds was  $20 \pm 0.66$  % in season II.

### 3.2. Salt Quality Parameters

The salt quality parameters and the percentage difference between the control and the experimental salt samples of the two salt pans (SP1 and SP2) during the three seasons are summarized in Table 3 and 4. In SP1 the maximum percentage variation in moisture

content observed between the control and the experimental samples is  $22.6 \pm 0.41\%$  in season I. The maximum percentage variation in insoluble impurities between the control and the experimental samples was  $16.4 \pm 1.2\%$  in season IV. The maximum percentage difference in calcium sulphate content between the control and the experimental salt samples ( $5.5 \pm 0.52\%$ ) was noticed during season I. Magnesium sulphate content of the salt samples varied by  $28.3 \pm 2.3\%$  in season IV. Likewise, magnesium chloride content showed the maximum percentage difference of  $20.2 \pm 1.2\%$  in season IV, between the control and the experimental samples. The maximum percentage difference in the sodium chloride content witnessed between the control and the experimental samples was  $3.6 \pm 0.19\%$  in season IV.

In SP2, the maximum percentage variation in moisture content observed between the control and the experimental samples was  $23.5 \pm 0.94\%$  in season II. The maximum percentage variation in insoluble impurities monitored between the control and the experimental samples was  $15.5 \pm 2.5\%$  in season I. The maximum percentage difference in calcium sulphate content ( $25.8 \pm 2.7\%$ ) between the control and the experimental salt samples was noticed during season I. The maximum percentage variation in magnesium sulphate content between the control and the experimental samples of the salt samples varied by  $27.1 \pm 1.3\%$  in season I. Likewise, magnesium chloride content showed the maximum percentage difference of  $20.7 \pm 1.2\%$  between the control and the experimental samples in season IV. Finally, the maximum percentage difference in the sodium chloride content monitored between the control and the experimental samples was  $4.5 \pm 0.40\%$ .

### 3.3 Amount of Sodium Chloride Harvested

The amount of sodium chloride harvested in the control and the experimental salt samples of SP1 and SP2 and the percentage variation is shown in table 5.

In SP1 the maximum amount of sodium chloride harvested in the control pond was  $37.5 \pm 2.3$  tonnes/ha/month during season IV and the maximum amount of sodium chloride harvested in the experimental ponds was  $43 \pm 2$  tonnes/ha/month during the same season.. The maximum percentage variation observed between the control and the experimental ponds of SP1 was  $15.1 \pm 0.68\%$  during season IV.

In SP2 the maximum amount of sodium chloride harvested in the control pond was  $33.5 \pm 1.9$  tonnes/ha/month during season IV and the maximum amount of sodium chloride harvested in the experimental ponds was  $39 \pm 1.05$  tonnes/ha/month during the same season.. The maximum percentage variation observed between the control and the experimental ponds of SP2 was  $16.9 \pm 0.84\%$  during season IV.

### 3.4. Heavy Metals

The concentration of heavy metals in the control and the experimental salt samples of the two salt works is presented in table 6. The amount of chromium was found to be  $2.8 \pm 0.14$  ppm in the sea salt sample and  $2.3 \pm 0.12$  ppm in the estuarine salt sample. The percentage difference of chromium between the control and the experimental samples was maximum ( $8.7 \pm 1.6\%$ ) in the salt work that used sea brine.

In the case of lead, the salt samples of SP1 accumulated the maximum ( $1.32 \pm 0.15$ ) ppm amount of lead in the control and  $1.27 \pm 0.15$  ppm in the experimental sample. The percentage difference in accumulation between the control and the experimental samples was greater in SP1 ( $5.8 \pm 0.30\%$ ) compared to SP2 ( $3.6 \pm 0.31\%$ ). The amount of nickel in the control and the experimental sea salt samples (SP1) was found to be 0.14ppm, whereas the value is less than 0.1ppm in the case of the estuarine (SP2) salt samples. While the percentage difference between the control and the experimental salt samples was zero in the case of sea salt samples the percentage difference between the control and the experimental salt samples was  $2.1 \pm 0.16\%$  in the case of estuarine salt samples.

The amount of iron in the salt samples of the control and the experimental ponds of SP1 were  $38 \pm 2.8$  and  $25 \pm 1.2$  ppb respectively, whereas the values were  $25.32 \pm 2.2$  and  $16 \pm 1.2$  ppb in the control and the experimental samples of SP2. The percentage difference in accumulation between the control and the experimental samples was greater in SP1 ( $36.1 \pm 2.2\%$ ) compared to SP2 ( $30.7 \pm 2.8\%$ ).

The amount of cobalt in the control and the experimental salt samples of SP1 was  $1.1 \pm 0.02$  and  $1.0 \pm 0.02$  ppm, respectively. Likewise, the amount of cobalt in the control and the experimental samples of SP2 was  $0.7 \pm 0.05$  and  $0.61 \pm 0.03$  ppm respectively. The percentage difference in accumulation of cobalt between the control and the experimental samples was greater in estuarine samples ( $12.1 \pm 1.6\%$ ) compared to ( $5.9 \pm 0.20\%$ ) in sea salt samples.

The amount of zinc in the salt samples of the control and the experimental ponds of SP1 was  $0.037 \pm 0.00$  and  $0.029 \pm 0.00$  ppm respectively; whereas the values were  $0.13 \pm 0.1$  and  $0.11 \pm 0.1$  ppm in the control and the experimental samples of SP2. The percentage difference in accumulation of zinc between the control and the experimental samples was greater in SP1 ( $20.5 \pm 1.4\%$ ) than SP2 ( $14.8 \pm 0.25\%$ ).

The heavy metal manganese in the control and the experimental salt samples of SP1 was  $0.1 \pm 0.1$  and  $0.09 \pm 0.02$  ppm respectively. Similarly, the amount of manganese in the control and the experimental samples of SP2 was  $0.065 \pm 0.02$  ppm and the percentage difference was zero. At the same time the percentage difference in accumulation of manganese between the control and the experimental samples was  $10.2 \pm 0.5$  in SP1.

## 4. Discussion

Evaporation is the chief process involved in the concentration of weak brine to saturation followed by crystallization in solar salt manufacture, which is affected by a number of physical factors like vapour pressure, temperature, wind velocity, humidity, the extent of the surface exposed and salinity. In the present study, the evaporation rate decreased from the primary to the tertiary condensers in both the control and the experimental samples of both the salt works in all the seasons. The decrease in evaporation rate observed was

due to the increase in salinity as the brine passes successively from the primary to the tertiary condensers. According to T. Masuzawa (1979) evaporation proceeds with great difficulty with rise in salinity. But in the crystallizers though the salinity is higher, the evaporation rate measured was more, than in the tertiary condenser. This is due to the reduction in the depth of the condenser ponds to crystallizers (35 to 15cm). As the depth decreases, the rate of evaporation increases, despite rise in salinity, where light can penetrate easily into the bottom brine accelerating evaporation (S.C Agarwaal, 1956). In the case of primary condensers of the two salt works the percentage increase in evaporation rate, observed between the control and the experimental ponds was 2 to 7%, whereas in the secondary condensers, it was 2 to 9%. Similarly, in the tertiary condensers the value increased by 8%. In the case of crystallizers, the increase in evaporation rate monitored was from 16.5 to 20% during the different seasons. The decrease in evaporation rate witnessed in the primary to the tertiary condenser samples is in agreement with the earlier reports of Chidambarathanu (1997) in the saltpans of Tuticorin District and with the saltpans of Kanyakumari District (A. Vaithyanathan, 2000)

#### 4.1. Evaporation Rate and Production

Generally in solar salt works the production will be from 10 to 250 tonnes per hectare per annum (M.U.Coleman and White M.A 1993) In temperate climate, the salt works can yield from 50 to 150 tonnes per hectare annually. The Indian sub-continent enjoys a tropical climate and hence the production is expected to be more. Salt production is directly related to evaporation rate and the present investigation has witnessed the same. In SPI, season IV recorded the maximum percentage increase in production of  $15.1 \pm 0.68 \%$  from the control to the experimental ponds and the maximum percentage increase in evaporation monitored in the same season was  $19.8 \pm 1.3 \%$ . In SP2, the maximum percentage increase in production between the control and the experimental salt samples recorded was  $16.9 \pm 0.84\%$  during season IV and the corresponding maximum evaporation rate observed was  $17.0 \pm 1.2 \%$

The increase in the evaporation rate and hence the increase in salt production observed was due to the inoculation of brine shrimp *Artemia franciscana* in the experimental ponds. *Artemia*, a filter feeder feeds on particulate matter of any origin and filters minute particles, ( $< 50 \mu\text{m}$ ) dispersed and suspended in salt water. Filtering of this minute particulate matter reduces the viscosity of brine thus increasing light penetration into the water. According to the earlier report *Artemia franciscana* had filtered better than *Artemia parthenogenetica* (T.Gopal, 1996). The increase in light penetration accelerates the evaporation rate and hence an increase in salt production.

In addition, presence of *Artemia* in the condensers causes a good density of halobacteria to develop in the crystallizer brine. The  $C_{50}$  terpenoid (carotenoid) present in the chloroplast of these halobacteria imparts a beautiful pleasing pink colour to the brine which traps more solar radiation and thus the brine temperature is increased (A.Oren and F. Rodriguez-Valera, 2001). The increase in brine temperature is greater than the temperature of the air above and hence the rate of evaporation is accelerated leading to an increase in production. In the present study, the increase in salt production ranged from 12.2 to 16.9 % and according to (Jones 1981) the increase in evaporation rate due to artificial colouring resulted in 15-20% increase in production.

#### 4.2. Salt Quality Enhancement

The salt quality parameters like moisture content, insoluble impurities, calcium sulphate, magnesium sulphate and magnesium chloride content decreased from the control to the experimental samples in all the seasons in both the salt works. As expected, the sodium chloride content increased from the control to the experimental samples. The reduction in moisture content was greater for the estuarine salt sample ( $19.8 \pm 1.2$  to  $23.5 \pm 1.4\%$ ) than for the sea salt sample ( $11.8 \pm 1.2$  to  $20.9 \pm 1.4\%$ ) In the case of insoluble impurities, both the control and the experimental samples witnessed only marginal differences. But the percentage difference in the case of estuarine sample was greater. The decrease in the calcium sulphate, magnesium sulphate and magnesium chloride content of the salt samples from the control to the experimental ponds showed variations. Compared to SPI, calcium sulphate decreased to a greater percentage in the case of SP2. The decrease in magnesium sulphate and magnesium chloride content is similar in both the salt works. The increase in sodium chloride content was  $3.5 \pm 0.02$  to  $3.6 \pm 0.19\%$  in the case of SPI, and  $4.2 \pm 0.30$  to  $4.5 \pm 0.40\%$  in the case of SP2 during the different seasons.

#### 4.3. Heavy Metals

Though heavy metals are needed for the living organisms, the concentration higher than the recommended level will cause serious effects on human beings and other living organisms. In the case of saltpans, heavy metal concentration depends on the source water intake and as evaporation proceeds, the concentration increases and hence the accumulation of heavy metals on salt samples is unavoidable.

The amount of chromium recorded in the salt samples is higher than the mean value (0.428 ppm) reported for the commercial sea salts (M.J. Atkinson and C. Bingman, J,2003). But it is interesting to note that the amount of chromium in the salt samples is lesser than (3.5ppm) recommended by the West Australian Food and Drug Regulations List.

. In the present study, higher level of lead has been reported in the sea salt samples compared to estuarine salt. This may be due to the heavily traveled road that runs along the Kanyakumari coast. High levels of lead often occur in water bodies near highways and large cities due to high gasoline combustion (I.M Banat et, al 1998). Kanyakumari being a tourist centre, the surface enrichment of lead would be by atmospheric input of automobile emission (S. Palanisamy, 2003). As the sea water forms the source for salt production in SPI, the salt samples were found to contain greater amount of lead. Earlier workers recorded a mean lead content of 0.535 ppm in the commercial sea salts. In both the samples the concentration of lead is below the recommended level (0.1 ppm). The amount of nickel in the salt sample is low and is comparable with that reported in the commercial sea salt samples which ranged from 0.099 to 0.135 ppm. According to the Western Australian Food and Drug Regulation List, the amount of nickel in the food samples is restricted to 5.5

ppm and the amount of nickel in the study samples is within the permissible limit. In the case of iron, though the iron content decreased from the control to the experimental ponds the value was found to be greater than that recorded in the commercial sea salt i.e  $15 \pm 13$ ppb. The amount of cobalt in the salt samples of the present study ranged from  $0.7 \pm 0.04$  to  $1.7 \pm 0.05$  ppm. The values observed were comparable with that recorded in the commercial sea salt samples (0.081ppm). Moreover, higher level of cobalt was observed in the salt samples of Kanyakumari District by the Salt Department of India as early as 1956.

The amount of zinc accumulated in the salt samples of SP1 and SP2 was comparable with the value in the commercial salt (0.032 ppm) which is closer to the value obtained in the present study. Moreover, Celtic sea salt is found to contain 0.0275 ppm of zinc which too parallels the present study.

Manganese belongs to the non critical trace element group. The result obtained in the present study is in agreement that reported for the commercial salt( 0.038 ppm )and for Celtic sea salt (0.018 ppm). Moreover, the amount of heavy metals (lead, chromium, nickel, zinc, iron cobalt and manganese) decreased from the control to the experimental samples except nickel in SPI and manganese in SP2. This is in accordance with the earlier report, which has detected high levels of heavy metals in the *Artemia biomass* and the cysts in a condition where heavy metals exist in the habitat (P.Sorgeloos,1980). The decrease in the heavy metal content in the experimental samples may be due to the bio-accumulation of these metals by *Artemia* or due to the tendency of *Artemia* in transferring these metals to the bottom mud or to the other organisms that inhabit the evaporation ponds of the salt works, which needs further study.

## 5. Conclusion

Inoculation of *Artemia* in the evaporation ponds of the two salt pans leads to increase in evaporation rate, increase in production of sodium chloride, decrease in the salt quality parameters like moisture content, insoluble impurities, calcium sulphate, magnesium chloride and magnesium sulphate content and increase in sodium chloride content. Except nickel and manganese in SP1, the concentration of heavy metals like chromium, lead, iron, cobalt and zinc decrease from the control to the *Artemia* inoculated ponds in both the salt works. These results confirm the fact that *Artemia* can be inoculated in the salt pans for quality and quantity enhancement of sodium chloride.

Stages	Season I			Season II			Season IV		
	C	E	% diff	C	E	% diff	C	E	% diff
Primary condenser	$17.6 \pm 1.1$	$18.1 \pm 0.65$	$2.2 \pm 0.2$	$13.9 \pm 3.2$	$14.8 \pm 1.2$	$6.7 \pm 0.23$	$21.8 \pm 1.4$	$22.6 \pm 1.5$	$3.6 \pm 0.18$
Secondary condenser	$11.6 \pm 0.96$	$12.1 \pm 0.34$	$3.1 \pm 0.2$	$9.7 \pm 1.6$	$10.1 \pm 0.45$	$4.4 \pm 0.36$	$13.5 \pm 0.98$	$14.7 \pm 0.89$	$8.8 \pm 0.42$
Tertiary condenser	$7.1 \pm 0.65$	$7.39 \pm 0.52$	$4.1 \pm 0.1$	$5.9 \pm 0.31$	$5.3 \pm 0.38$	$6.8 \pm 0.4$	$6.9 \pm 0.44$	$7.1 \pm 0.36$	$2.8 \pm 0.22$
Crystallizer	$9.7 \pm 0.88$	$11.3 \pm 0.22$	$16.5 \pm 0.51$	$7.2 \pm 0.47$	$8.4 \pm 1.33$	$17.1 \pm 0.24$	$10.2 \pm 0.25$	$12.1 \pm 0.68$	$19.8 \pm 1.3$

Table 1: Evaporation rate ( $Lm^{-2} day^{-1}$ ) recorded in the control and the experimental ponds of SP1

Stages	Season I			Season II			Season IV		
	C	E	% diff	C	E	% diff	C	E	% diff
Primary condenser	$14.5 \pm 1.2$	$15.1 \pm 0.98$	$4.1 \pm 0.18$	$12.9 \pm 1.4$	$13.4 \pm 1.5$	$3.8 \pm 0.12$	$15.4 \pm 1.4$	$16.4 \pm 1.1$	$6.8 \pm 0.29$
Secondary condenser	$6.7 \pm 0.98$	$7.2 \pm 1.1$	$7.4 \pm 0.24$	$7.6 \pm 0.97$	$7.9 \pm 0.90$	$6.7 \pm 0.41$	$10.8 \pm 1.1$	$11.2 \pm 0.9$	$4.25 \pm 0.23$
Tertiary condenser	$4.4 \pm 0.63$	$4.8 \pm 0.45$	$9.7 \pm 0.36$	$3.7 \pm 0.45$	$4.1 \pm 0.41$	$10.8 \pm 0.48$	$5.4 \pm 0.37$	$5.7 \pm 0.24$	$5.5 \pm 0.18$
Crystallizer	$6.4 \pm 0.72$	$7.5 \pm 1.2$	$17 \pm 0.81$	$6.0 \pm 0.62$	$7.2 \pm 0.73$	$20 \pm 0.66$	$8.2 \pm 0.42$	$9.6 \pm 0.19$	$17.0 \pm 0.59$

Table 2: Evaporation rate ( $Lm^{-2} day^{-1}$ ) recorded in the control and the experimental ponds of SP2

Quality parameters	Season I			Season II			Season IV		
	C	E	% diff	C	E	% diff	C	E	% diff
Moisture content	$7.8 \pm 0.33$	$6.0 \pm 0.25$	$22.6 \pm 0.41$	$7.1 \pm 0.32$	$6.3 \pm 0.37$	$11.8 \pm 0.68$	$7.3 \pm 0.27$	$5.8 \pm 0.41$	$20.9 \pm 1.4$
Insoluble impurities	$0.52 \pm 0.06$	$0.50 \pm 0.05$	$3.8 \pm 0.18$	$0.67 \pm 0.08$	$0.62 \pm 0.11$	$7.8 \pm 1.2$	$0.59 \pm 0.06$	$0.49 \pm 0.07$	$16.4 \pm 1.2$
CaSO <sub>4</sub>	$0.327 \pm 0.03$	$0.309 \pm 0.03$	$5.50 \pm 0.52$	$0.338 \pm 0.06$	$0.327 \pm 0.04$	$3.2 \pm 0.18$	$0.377 \pm 0.06$	$0.360 \pm 0.03$	$4.5 \pm 0.20$
MgSO <sub>4</sub>	$1.3 \pm 0.04$	$1.03 \pm 0.21$	$20.7 \pm 2.3$	$1.12 \pm 0.16$	$0.96 \pm 0.04$	$13.3 \pm 1.4$	$1.2 \pm 0.04$	$0.86 \pm 0.21$	$28.3 \pm 2.3$
MgCl <sub>2</sub>	$1.09 \pm 1.1$	$0.89 \pm 0.07$	$18.3 \pm 1.20$	$0.98 \pm 0.20$	$0.90 \pm 0.09$	$8.1 \pm 0.6$	$1.0 \pm 0.02$	$0.80 \pm 0.10$	$20.0 \pm 1.2$
NaCl	$88.5 \pm 2.2$	$91.4 \pm 2.8$	$3.3 \pm 0.07$	$88.1 \pm 2.1$	$90.8 \pm 2.9$	$3.0 \pm 0.12$	$88.9 \pm 2.3$	$92.0 \pm 3.7$	$3.6 \pm 0.19$

Table 3: Salt quality parameters in the control and experimental salt samples of SP1

C- Control; E-Experimental

Quality parameters	Season I			Season II			Season IV		
	C	E	% diff	C	E	% diff	C	E	% diff
Moisture content	10.7 ± 1.2	8.6 ± 0.72	19.8 ± 1.0	10.6 ± 1.2	8.1 ± 0.51	23.5 ± 0.94	10.3 ± 1.6	7.0 ± 0.61	22.3 ± 1.1
Insoluble impurities	1.99 ± 0.58	1.68 ± 0.63	15.5 ± 2.5	1.45 ± 0.22	1.1 ± 0.03	24.1 ± 1.6	1.09 ± 0.04	1 ± 0.05	8.2 ± 1.4
CaSO <sub>4</sub>	0.422 ± 0.04	0.313 ± 0.06	25.8 ± 2.7	0.379 ± 0.08	0.316 ± 0.03	16.62 ± 1.5	0.352 ± 0.08	0.307 ± 0.09	12.7 ± 0.9
MgSO <sub>4</sub>	1.62 ± 0.27	1.18 ± 0.12	27.1 ± 1.3	1.53 ± 0.20	1.32 ± 0.08	13.7 ± 1.1	1.6 ± 0.04	1.4 ± 0.19	12.5 ± 1.1
MgCl <sub>2</sub>	1.36 ± 0.23	1.1 ± 0.07	19.1 ± 0.99	1.09 ± 0.18	0.91 ± 0.1	16.5 ± 1.3	1.11 ± 0.04	0.88 ± 0.29	20.7 ± 1.2
NaCl	83.6 ± 0.8	87.4 ± 1.2	4.5 ± 0.40	84.8 ± 1.6	88.4 ± 1.9	4.2 ± 0.30	85.9 ± 1.1	89.7 ± 1.0	4.3 ± 0.21

Table 4: Salt quality parameters in the control and the experimental salt samples of SP2  
C- Control; E-Experimental

Seasons	SP1			SP2		
	C	E	% diff	C	E	% diff
Season I	27 ± 1.5	30 ± 1.8	12.2 ± 1.1	25.5 ± 2.1	29 ± 1.4	14.3 ± 0.96
Season II	31 ± 1.6	35 ± 1.8	13.8 ± 0.84	27.5 ± 1.2	32 ± 1.7	15.5 ± 0.88
Season IV	37.5 ± 2.3	43 ± 2.0	15.1 ± 0.68	33.5 ± 1.9	39 ± 1.05	16.9 ± 0.84

Table 5: Salt harvested from the control and the experimental ponds of SP1 and SP2 at different seasons (tonnes /ha/month)

Heavy metals	SP1			SP2		
	C	R	%diff	C	E	%diff
Cr	2.8 ± 0.14	2.3 ± 0.12	18.7 ± 1.6		0.61 ± 0.03	17.1 ± 0.76
Pb	1.32 ± 0.15	1.27 ± 0.11	3.6 ± 0.21		0.34 ± 0.03	5.8 ± 0.30
Ni	0.14 ± 0.04	0.14 ± 0.03	0.00		0.089 ± 0.00	2.1 ± 0.16
*Fe	38 ± 2.8	25 ± 1.2	36.1 ± 2.2		16 ± 1.2	30.7 ± 2.8
Co	1.1 ± 0.03	1.0 ± 0.02	5.9 ± 0.20		0.61 ± 0.03	12.1 ± 1.6
Zn	0.037 ± 0.00	0.029 ± 0.00	20.5 ± 1.4		0.11 ± 0.1	14.8 ± 0.25
Mn	0.10 ± 0.01	0.10 ± 0.0	0		0.059 ± 0.00	8.6 ± 0.24

Table 6: Heavy metal accumulation in the control and the experimental salt samples SP1 and SP2

## 5. References

- i. Hocquet, J.C., Hocquet J. 1987. The history of a food product. Salt in Europe. A bibliographic review. Food and Foodways Vol. 1, pp. 425-477
- ii. Young, G. 1977. Salt the Essence of Life. National Geographic, pp 381-401.
- iii. Davis.J.S. 1974. Importance of microorganisms in solar salt production. Proc. 5<sup>th</sup> Intsymp.Salt.Vol.1.Northern Ohio Geological Society, Inc., Cleveland Ohio
- iv. Tackaert, W., Sorgeloos, P.1993. The use of brine shrimp *Artemia* in biological management of solar salt works. Pro. 7<sup>th</sup> Int. symp. Salt Vol.1, pp 111-616. Elsevier science publishers B.V., Amsterdam.
- v. Joseph Davis and Morio Giordano 1996. Biological and physical events involved in the origin, effects and control of organic mater in solar salt works.
- vi. A.I.Vogel, A text book of Quantitative Inorganic Analysis 3<sup>rd</sup> Edn., ELBS and – Longman's London, 1969.
- vii. T. Masuzawa , Second World salt symposium salt, p 463-673,1979
- viii. S.C Aggarwal, The salt Indurhy in India. Themanager of Publications
- ix. A. Chidambarthanu, Ph.D thesis M.S. University Tiruneveli, 1997
- x. C.Vaithyanathan. Ph.D. Thesis M.S.Unversity, Tiruneveli, 2000.
- xi. Browne, R.S., Competition experiments between parthenogenetic and sexual strains of the brine shrimp, *Artemia Salina* Ecology, 61(3): 471-774.
- xii. Aharon Oren, Francisco Rodriguez valera. The contribution of halophilic Bacteria to the red colouration of saltern crystallizer ponds FEMS Microbiology Ecology 36 (2001)12 3-130
- xiii. Jones, A.G; Ewing, C.M and Melvin, M.V., 1981, Biotechnology of solar salt fields. Hydrobiologia, 82:391-406.
- xiv. M.J. Atkinson and C.B.ingman. Elemental composition of commercial sea salts Journal of aquaculture and Aquatic Sciences Vol. 111, No:2 Page 39 (2004)
- xv. Banat, I.M, Hassan E.S., Shahawi., Abu Hilal A.H.1998. Post Gulf war assessment of nutrients, heavy metal ions, hydrocarbons and bacterial pollution levels in the United Arab Emirates Coastal waters. Environ. Int., 24:109-116.
- xvi. S.Palani Chamy, A. Rajendran and S.Ragumaran 2004, Heavy metal concentrations in some marine Algae from the Gulf of Mannar, South east coast India. Seaweed Res. Utlin 26 Spl issue 107-110
- xvii. P.Sorgeloos, P., 1983 Brine Shrimp *Artemia* in coastal salt work inexpensive source of food for vertically integrated aquaculture. Aquaculture Magazine, 9:25-27
- xviii. [http:// www.Celtic.seasalt.com/saltofflife/Celtic salt .html](http://www.Celtic.seasalt.com/saltofflife/Celtic%20salt.html).