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SOLAR SALT TECHNOLOGY IN GHANA – A CASE STUDY OF SMALL SCALE SALT WINNING PROCESS

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Abstract

Generally, unrefined salt from local small scale salt producers does not meet the standard specifications of the Ghana Standard Board. In this study, the traditional small scale salt production process was studied. Brine and salt samples from the various stages of the traditional process were analysed for calcium, sulphate, magnesium and chloride contents in order to propose a method to improve the quality of output. The brine samples contained low levels of calcium (ranging from 0.14% to 0.01%), and high levels of magnesium (ranging from 1.04% to 4.49%). These two elements constitute the two main elemental impurities found in common salt. Samples of salt produced also contain high levels of magnesium, averaging 0.98 per cent, above the recommended maximum level of 0.1 per cent by the Ghana Standard Board for unrefined edible salt. The study is significant in that the findings form the basis for recommending an alternative method for minimizing magnesium content in the salt produced. This will enhance the quality of salt produced by the small scale producers. The method eliminates the recycling of bittern in the traditional process and also introduces a salt washing operation.

Résumé

MENSAH B. & BAYITSE R.: *Technologie solaire de sel au Ghana - Une étude de cas du procé dé de salinage peu important.* En général le sel non raffiné de saliniers locaux peu importants ne correspond pas aux spécifications normales du Conseil Ghanéen de Normalisation. Dans cette étude le procédé traditionnel relatid à la production de sel peu important, était étudié. L'eau salée et les échantillons de sel prélevés de différents stades du procédé traditionnel étaient analysés pour les teneurs en calcium, en sulfate, en magnésium et en chlorure afin de proposer une méthode pour améliorer la qualité de la production. Les échantillons contenaient de faibles niveaux de calcium et de niveaux élevés de magnésium, les deux impuretés élémentaires principales qui se trouvent dans le sel ordinaire. Une autre méthode pour réduire au minimum la teneur en magnésium du sel produit est proposée. La méthode proposée exclut le recyclage de butor du procédé traditionnel et introduit aussi une opération de lavage de sel.

Introduction

Common salt, chemically known as sodium chloride, is one of the most important raw materials in the world. It has both food and non-food uses. Salt is used widely as food supplement, partly as a physiological need and partly for food flavoring. In animal husbandry, salt is mainly used as food supplement for livestock. As an industrial raw material, salt is the basic raw material for the production of a large number of inorganic chemicals such as caustic soda, chlorine, soda ash, sodium sulphate and hydrochloric acid. It also finds uses in a number of industries, such as soap manufacture, dyes, leather, textiles, regeneration of exchange resins, and in the food industry, such as canning of vegetables, meat and fish. Salt is also used in the preparation of various products including physiological solutions; for example, tooth pastes and solutions for cleaning wounds.

Salt production from seawater or from natural brine by solar evaporation is the most common method of producing salt, and this method has been practised for centuries along sea coasts in many countries. Additionally, dug out wells near the coast also serve as sources of brine for salt production. Solar evaporation from seawater or brine, is basically a fractional crystallization process using the sun as source of energy. As the density of the brine, which is initially about 3.5 ^{0}Baumé (1.024 specific gravity) for seawater, increases owing to evaporation, certain chemical compounds found in seawater or any brine source which are less soluble than sodium chloride, such as calcium and iron compounds, start to crystallize or precipitate out of solution first. Sodium chloride begins to crystallize out when brine density reaches 25.7 ^{0}Baumé or at specific gravity of 1.217 (Pandey, 1997). Other compounds, mainly magnesium salts, which are more soluble than sodium chloride, remain in solution until the sodium chloride has crystallized.

There are variations in the solar evaporation process resulting in varying product quality. Basically, there are two main variations, namely production from salt works (done under controlled conditions) and production from salt winning sites (under uncontrolled conditions). In general salt from saltworks are of better quality, containing less impurities such as calcium and magnesium compounds, than salt from salt winning sites which contain more of such impurities.

A saltwork is defined as a flat land location where facilities have been constructed to control seawater inlet and arranged a brine flow through evaporating ponds, in accordance with calculated parameters such as brine flow rate, rate of evaporation, specific gravity of brine, with a view of concentrating the seawater sequentially by solar evaporation until salt is crystallized in crystallizing pans (Garcia, 1993). The flow of brine from pond to pond is controlled so as to effect selective crystallization of the different compounds such as calcium and magnesium salts found in seawater in addition to sodium chloride. Such selective crystallization produces a better quality common salt.

Salt winning sites are sites where sea water or brine is allowed to evaporate to dryness. Salt obtained from such sites contain other salts, such as calcium and magnesium salts, alongside sodium salts. There is no control over the evaporation process and, as such, common salt produced from salt winning sites are generally of low quality.

In Ghana, production of common salt is an age-old traditional industrial activity in many coastal communities. The industry is characterized by small, medium and large scale producers scattered along coastal districts such as Dangbe East and West, Ga, Awutu-Efutu Gomoa, Keta-Ketu, and Mfantseman districts. The national salt production is about 200,000 metric tones annually.

Solar evaporation is the main method of salt production in Ghana as described by Owusu (1971). Owusu also described other methods of salt production such as the stove method. Production from saltworks are practiced by large scale producers whilst salt winning is practiced by medium and small scale producers. A recent study (Mensah & Bayitse, 2005) to evaluate the quality of local crude salts from 13 production sites showed a generally low quality product as compared with the standard requirement of the Ghana Standard Board. There is, thus, the need to improve the quality of such crude salt through appropriate technological intervention in the production process. Consequently, this work is designed to study the traditional small scale salt winning process to gather data to assist in proposing appropriate methods of improving upon the quality of the product. The small and medium scale salt producers contribute significantly to national salt requirement, and the need to improve upon their process and product quality cannot be over emphasized.

Study area

Nyanyanu, a coastal town in the Gomoa District in the Central Region, was the study area (Fig. 1). Salt winning is a major occupation in the area involving about 300 people**.** This site was selected because one of the samples in a previous study (Mensah & Bayitse, 2005) was taken from the area. Nyanyanu has a large level land with the area experiencing wind speeds between 6.0-9.7 knots. There are two rainy seasons in the year, the major one occurring in the months of May and June and the minor one in October. Monthly mean rainfall values of 217 mm and 64 mm have been recorded for the major and minor seasons, respectively. There are no salt production activities during the raining seasons. Relative humidity in the area varies between 82-98%. The temperature regime varies from maximum values of 31-34 ^{o}C to minimum temperatures of 23 - 25 ^{o}C. These conditions make the place suitable for solar evaporation.

The salt pans are constructed with concrete floors and separated by concrete or mud ridges. The pans which are roughly rectangular in shape are in different dimensions, about 9-12 m in width and 13-15 m in length**.** The height of initial brine in the pans also ranges from 1.8-5 cm. The brine in the pan is left to evaporate using the sun as source of energy. After 2-3 days, sand and other insoluble materials settle and are pushed away into a box at one corner of the salt pan (Plate 3 showing the box). The clean brine is then allowed to evaporate until salt crystallizes out. This takes about 6-12 days depending on factors such as the height of the original brine in the pan, prevailing temperature regime and air humidity. The day the salt is harvested often depends on the size of salt crystals and also the experience of the operator. The salt is harvested into woven baskets using

Fig. 1. Map of the Central Region, Ghana, showing Nyanyanu

Description of salt winning process in Nyanyanu

In Nyanyanu, salt is produced from natural brine obtained from dug out wells (Plates 1-3). The dug out wells are rectangular, measuring about 4 m by 3 m, with varied depths estimated to b**e** between 3-5 m. The brine is pumped from the wells into salt pans constructed close to the wells.

PLATE 1 Showing dug out well and salt pans

PLATE 2 Salt pan being fed with brine from dug out well

shovels. The harvested salt is then dumped onto concrete floors in wooden warehouses for entrained bittern to drain off. It is later bagged for sale. After harvesting, the bittern is left in the salt pan where fresh brine from the dug out well is pumped into the pan to mix with the bittern, and the winning process starts again as shown in Scheme 1.

Experimental

Samples of brine during salt production were taken from eight different salt pans in February and April, 2005. From each salt pan four different samples were collected as the production process progressed with time. The four samples were as follows:

a) Initial brine – this was taken on the first day of production process when brine from dug out well was freshly pumped into salt pan containing left over bittern from a previous salt production cycle.
b) Brine at first visible sign of salt crystals in the salt pan. The sampling time for this sample varied between 6 and 8 days from the first day.
c) Bittern – brine left in salt pan after harvesting salt crystals. This was done, on the average, about 12 days from the start of production.
d) Harvested salt crystals.

Sample collection

Brine samples - each salt pan was roughly divided into four quadrants and 250 ml sub samples were taken from each quadrants using plastic bottles. These sub samples were combined into one bulk sample of 1 litre each.

Salt samples - salt crystals from each pan was harvested in woven baskets. Portions of salt samples were taken from each basket and combined to give one bulk sample of about 600 g.

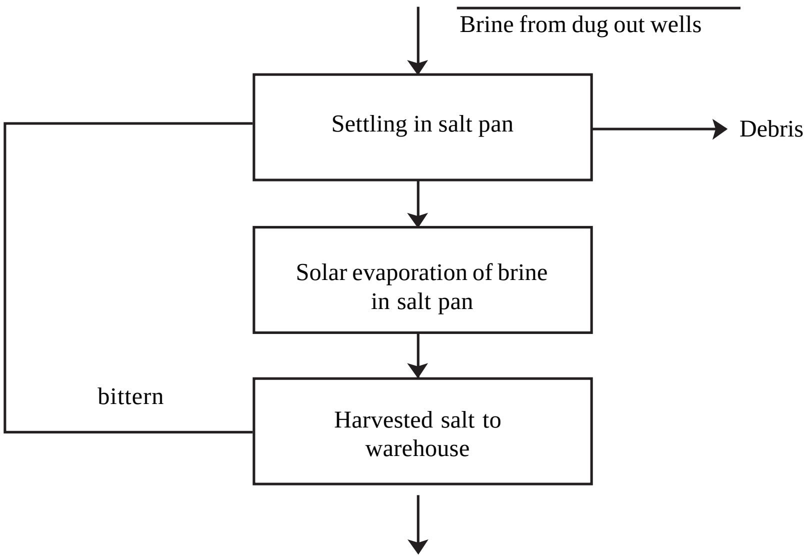
PLATE 3 Salt pans showing wooden boxes

major elements (cations and anions) used in assessing salt quality (GS 152, 1993). The specific gravity of each brine sample was also determined using specific gravity bottles. The brine samples were filtered before they were analyzed.

Standard analytical methods were employed for the determinations. Sulphate was determined by gravimetric method using barium chloride as described in AOAC (1975). Chloride was determined by titration with silver nitrate using potassium dichromate indicator. Total hardness and calcium were determined by EDTA titration. Magnesium was calculated from the difference between the total hardness and the calcium hardness (Basseggio, 1984; APHA, 1998).

Methods of analysis

The initial brine height in each pan was measured. Each brine and salt sample were analyzed for their chloride, sulphate, calcium and magnesium contents, since these constitute the



Scheme 1. Solar salt winning

Results

Characteristics of brine samples in salt pans

The physical and chemical characteristics of brine samples obtained from the salt pans at the different stages of the solar salt winning process are shown in Tables 1-4.

The specific gravity of initial brine in the salt pans ranges from 1.05 to 1.11, with a mean value of 1.09 and a standard deviation of 0.02. The results show that initial brine in the salt pans contained varied amounts of magnesium, ranging from 0.61 to 1.48 per cent with a mean value of 1.04 per cent and standard deviation of 0.28 per cent (Table 1). Levels of total chlorides range from a minimum 3.6 per cent to a maximum level of 8.9 per cent with a mean of 6.91 ± 1.66 per cent. The mean values of other ions, namely calcium and sulphate are 0.14 ± 0.03 per cent and 1.37 ± 0.34 per cent, respectively.

The specific gravity of brine samples at the points where sodium chloride begins to crystallize ranges from 1.21 to 1.25 with a mean of 1.23, and a standard deviation of 0.02 as shown in Table 3. The mean values of Mg, Ca, sulphate and total chlorides in solution are 2.46 ± 0.44, 0.07 ± 0.04 , 3.70 ± 0.77 and 15.2 ± 0.62 per cent respectively. After winning the salt, the bitterns left behind have a mean specific gravity of 1.26 ± 0.02 with a maximum value of 1.29 and a minimum value of 1.21 (Table 3). The mean values of Mg, Ca, sulphate and total chlorides in the bitterns are 4.49 ± 0.92, 0.01 ± 0.002 , 5.16 ±1.18 and 15.00 ± 0.46 per cent, respectively.

Characteristics of salt samples

Table 4 shows the characteristics of samples of salts obtained from the salt pans studied. Average total chloride calculated as sodium chloride content of the salt samples is 89.59 per cent with a standard deviation of 2.93 per cent. The mean values of Mg, Ca, and sulphate found in the salt samples are 0.98 ± 0.07, 0.08 ± 0.06 and 1.36 ± 0.22 per cent, respectively.

Discussion

Characteristics of initial brine samples

Initial brine sample in each salt pan is composed of freshly pumped brine from dug out well into the salt pan containing bitterns from left over from previous salt harvest. The initial brine heights in the salt pans ranging from 2.4 to 3.7 cm are lower than the reported brine height of 15 - 40 cm for best practice in solar salt production (Garcia, 1993; Owusu, 1971; Lartey, 1997). The results of

TABLE 1

Characteristics of Initial brine

Salt pans	*Brine height/cm*	*Specific gravity at 26 °C*	*Mg, %w/w*	*Ca, %w/w*	*SO_4, % w/w*	*Cl, %w/w*
D	3.1	1.11	1.48	0.09	1.90	8.90
B	3.5	1.08	1.05	0.13	1.40	6.50
F	2.4	1.09	1.36	0.15	1.30	8.10
D2	3.1	1.10	1.02	0.15	1.60	6.80
B2	3.5	1.05	0.61	0.13	0.83	3.60
A2	3.1	1.10	0.96	0.15	1.50	8.30
H	3.7	1.08	0.81	0.15	1.00	6.00
C	3.5	1.09	1.00	0.18	1.40	7.10
Mean		1.09	1.04	0.14	1.37	6.91
S. D.		0.02	0.28	0.03	0.34	1.66

TABLE 2

Characteristics of brine at the beginning of salt crystalisation

Salt pans	*Specific gravity at 26 °C*	*Mg, %w/w*	*Ca, %w/w*	*SO_4 % w/w*	*Cl, %w/w*
D	1.21	2.39	0.03	2.90	16.1
F	1.23	2.07	0.10	4.50	15.1
D2	1.25	3.09	0.03	4.20	14.7
C	1.22	2.30	0.10	3.20	14.9
Mean	1.23	2.46	0.07	3.70	15.2
S.D.	0.02	0.44	0.04	0.77	0.62

TABLE 3

Characteristics of bittern samples

Salt pans	*Specific gravity at 26 °C*	*Mg, %w/w*	*Ca, %w/w*	*SO_4, % w/w*	*Cl, %w/w*
D	1.25	3.84	0.012	4.50	14.16
B	1.24	3.87	0.014	4.20	15.70
F	1.25	5.57	0.016	4.40	15.70
D2	1.29	5.36	0.012	7.00	14.70
B2	1.26	3.75	0.016	4.90	15.00
A2	1.29	5.39	0.012	6.90	14.60
H	1.25	3.62	0.016	4.20	14.70
C	1.25	3.39	0.016	4.50	15.00
Mean	1.26	4.49	0.010	5.16	15.00
S.D.	0.02	0.92	0.000	1.18	0.46

chemical analysis obtained for the initial brine samples with a mean specific gravity of 1.09 show high levels of magnesium averaging 1.04 per cent w/w compared with levels obtained for natural brine solutions with similar or higher specific gravity values. For example, a lower magnesium level of 0.43 per cent had been reported for natural brine solutions having specific gravity of 1.09 (Basseggio, 1984). Lartey (1997) reported another low magnesium level of 0.61 per cent for brine solution having a slightly higher specific gravity of 1.13 in a solar salt production process. The high magnesium level obtained in this study is due to the presence of bitterns left in the salt pan after previous salt harvesting from the respective pans. The bitterns contain high amounts of dissolved magnesium compounds such as magnesium sulphate and magnesium chloride. Since magnesium is a major constituent that affects salt quality, it is always advantageous to use brine solutions with less magnesium content.

The mean value of 0.14 per cent calcium content in the initial brine is similar to reported value for brine solution with specific gravity of 1.09 (Basseggo, 1984). However, in a similar solar salt production process, Lartey (1997) reported very low levels of calcium between 0.01 - 0.05 per cent for brine solutions with specific gravity of 1.03 to

TABLE 4

Characteristics of salt samples

Salt Pans	*Mg % w/w*	*Ca %w/w*	*SO_4, % w/w*	*Cl, %w/w*	*Cl, cal as NaCl %w/w*
D	1.00	0.14	1.50	52.41	86.34
B	0.93	0.06	1.20	54.33	89.50
F	1.02	0.12	1.10	54.45	89.71
D2	0.91	0.01	1.50	55.07	90.73
B2	1.08	0.12	1.60	54.33	89.51
A2	0.87	0.06	1.20	53.64	88.37
H	1.03	0.01	1.60	52.65	86.74
C	0.99	0.15	1.10	58.15	95.80
Mean	0.98	0.08	1.36	54.38	89.59
St Dev	0.07	0.06	0.22	1.78	2.93
GSB*	0.1max	0.2 max	0.95 max		97 min

* Source - GS 152 , 1993. Spices and condiments -Specification for unrefined edible salt, Ghana Standards Board.

1.17, respectively.

The mean chloride level of 6.91 per cent obtained in this study compares favourably with reported value of 6.5 per cent brine solution of specific gravity 1.09 (Basseggio, 1984). The initial brines encountered in this study are, thus, more concentrated than fresh seawater which has an average specific gravity of 1.024, and a chloride concentration of 2.88 per cent (Owusu, 1971; Lartey, 1997). This initial high concentration means salt crystallization will take shorter time compared to that taken directly from the sea. Indeed, these results can be regarded as average values, for slightly lower or higher values can be obtained at other locations.

The salt pans are fed with brine from dug out wells fed through seawater seepage from the nearby sea. It was noted that brines from the wells are of varied specific gravities and, as such, operators often combine brine from two or more dug out wells, where possible, in order to obtain maximum brine strength for their operations. However, weak brines are also used when there is not enough strong brine in other wells. Analysis of brine samples from two dug out wells (combined brine from two wells) used to feed the salt pans indicates an average specific gravity of 1.08 and mean Mg content of 0.52 per cent, a level which is comparable to reported values of brines with similar strength as indicated above.

Characteristics of brine samples at beginning of sodium chloride crystallization

The results of analysis obtained for brine samples at the beginning of salt crystallization are shown in Table 2. The average specific gravity at which the salt began to crystallize was 1.23, a value which is comparable to the 1.22 reported in other studies (Pandey, 1997; Basseggio, 1984). The mean value of calcium in the above brine samples is 0.04 per cent, a value lower than that in the initial brine (0.14%). As the brine gradually becomes concentrated due to evaporation of water, calcium compounds, in the form of calcium carbonate and calcium sulphate, begin to precipitate out of solution after a brine specific gravity of 1.07. The precipitation of calcium compounds continues until brine specific gravity reaches 1.13, where most of the calcium compounds would have precipitated out, the rest are removed as brine becomes more concentrated (Pandey, 1997). This accounts for the low concentration of calcium in the brine at the beginning of salt crystallization. The magnesium compounds, however, remain in solution until most of the salt (NaCl) had separated out of the brine solution before they precipitate out.

Characteristics of bittern samples

The bittern samples have a mean specific gravity of 1.26 ± 0.02 (Table 3), which is equal to the 1.26 specific gravity reported by Lartey (1997) but higher than the 1.22 and 1.24 reported by other workers for bittern samples (Owusu, 1971; Basseggio, 1984) . The mean magnesium content of 4.49 per cent obtained is also higher than reported values of 4.24 and 3.49 per cent. The high magnesium content and corresponding low levels of calcium make the bitterns produced suitable for the recovery of magnesium as a by-product of the solar salt production.

Characteristics of salt samples

Samples of salt produced from the salt pans studied have a mean magnesium content of 0.98 per cent. This average value is well above the specified maximum requirement of 0.1 per cent by the Ghana Standard Board for unrefined edible salt (GS 152, 1993). Earlier discussions had indicated high magnesium in the original brine mainly as a result of the addition of recycled bitterns containing high magnesium salts. Furthermore, allowing crystallization to proceed beyond brine with a specific gravity of 1.25 increases the precipitation of other salts, mainly magnesium, resulting in high magnesium levels in the resultant salt samples. Such excess magnesium content may not be easily washed away by dilute brine solutions in situations where washing facilities exist. Indeed unacceptable high levels of magnesium ranging from 0.14 to 1.51 have also been reported in other locally produced unrefined salts (Owusu, 1971; Mensah & Bayitse, 2005). Magnesium exists in common salt mainly as magnesium sulphate and magnesium chloride. Presence of high levels of magnesium sulphate imparts bitter taste to the salt and also renders it moist.

Calcium content in the salt samples ranges from 0.01 to 0.15 per cent with a mean value of 0.08 per cent w/w. These values are below the GSB maximum requirement of 0.2 per cent. The low level of calcium in the salt may also be attributed to the fact that calcium compounds begin to precipitate out of solution before the salt (NaCl) begins to separate out, and the precipitated calcium compounds are removed together with other debris before salt begins to crystallize. Calcium content in local unrefined salts has been found to be in the range of 0.1 per cent to as high as 0.56 per cent (Owusu, 1971; Mensah & Bayitse, 2005). This implies that the calcium levels in some local salt samples are within GSB's specifications whilst others are not. However, for the process studied in this work, magnesium seems to be the major elemental impurity in the salts produced, and, therefore, any proposed improvement on salt winning would have to concentrate on minimizing magnesium content.

Conclusion

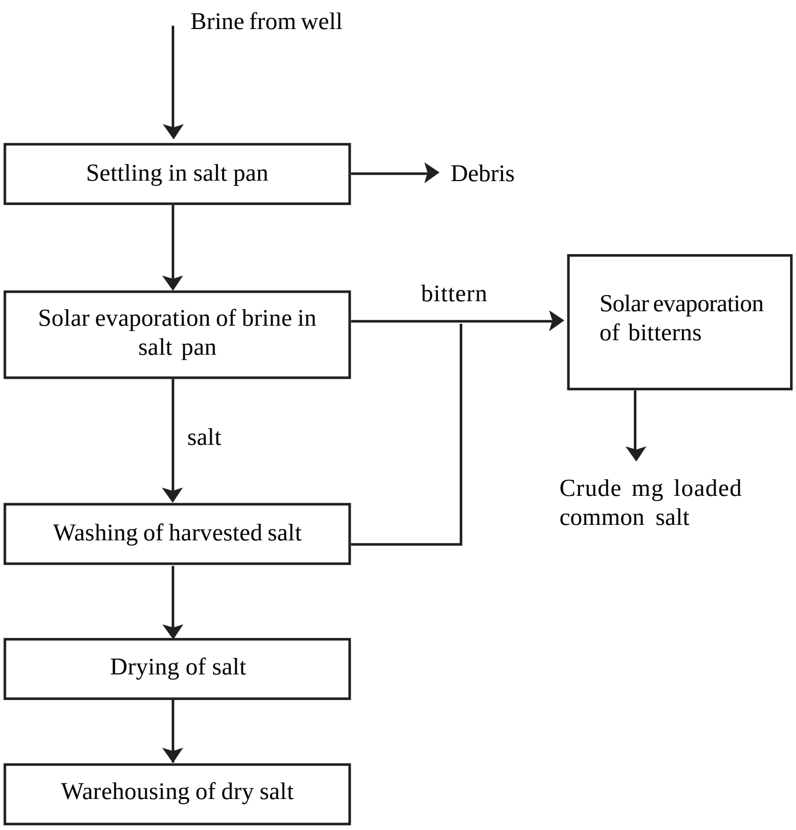
The quality of salt obtained from the case study area does not conform to the Ghana Standard's specification for unrefined salt. The major problems or contaminants are high magnesium content of 0.98 per cent and high sulphate content of 1.36 per cent in the salt samples compared to permissible levels of 0.1 and 0.95 per cent, respectively, recommended by the Ghana Standard Board. The high levels of these contaminants can be attributed to the method used whereby bitterns containing appreciable levels of magnesium and sulphate, are recycled into fresh brine for salt production. The mean value of 89.59 per cent sodium chloride content of the salt is also lower than the minimum permissible level of 97 per cent. In order to reduce the level of contaminants and increase quality of salt produced to acceptable limits, a processing method (Scheme 2), which eliminates the recycling of bittern in the traditional process and also introduces a salt washing operation has been proposed.

Recommendations

The salt winning operators operate mainly as single owners having multiple salt pans. In the absence of a large scale salt works, it is proposed that the process being used by these small scale operators be upgraded within the context of the existing socio-economic environment that will still keep the people in business and also produce better quality salt. From the discussions above, the following scheme is suggested.

(1) The depths of salt pans be increased to contain initial brine heights between 20-30 cm to enable better separation of the different compounds in the brine.

(2) The density of brine during evaporation be monitored to prevent the brine strength from exceeding 30 ^{0}Bé. For beyond this strength more contaminants such as magnesium salts precipitate which are not



Scheme 2. Recommended solar salt winning

easily removed through washing of the salt.

(3) A simple salt washing equipment be introduced to wash off, using dilute brine, some of magnesium salts and other contaminants which may dissolve in dilute brines. There is the need to carefully monitor this process to reduce the amount of sodium chloride that will also dissolve and decrease yield.

(4) Bitterns should not be recycled but be evaporated in separate pans for the recovery of magnesium (Lartey, 1997) as a by-product for income generation.

(5) A dryer, possibly a solar dryer, be introduced to dry the salt before warehousing and packaging.

The proposed scheme is represented in Scheme 2. However, this scheme will have to be studied to establish specific parameters for the desired quality of salt to be produced.

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References

AOAC (Association of Official Analytical Chemist), (1975) *Official Methods of Analysis of the Association of Official Analytical Chemists*, 12th edn. Washington D.C. pp. 626-628.

APHA (1998) *Standard Methods for the Examination of Water and Waste Water,* 26th edn. American Public Health Association, 1015 Fifteenth Street NW, Washington DC, 2005-2605. 3-82 pp.

BASSEGGIO, G. (1984) Composition of Sea Water and Its Concentrates. *Fourth International Symposium on Salt- Northern Ohio Geological Society.*

GARCIA A. (1993) *Solar Salt Technology* (P. C. Acquah ed.). Minerals Commission, Ghana

GS 12 (1993) *Spices and Condiments-Specification for Unrefined Edible Salt.* Ghana Standards Board, Accra, Ghana.

LARTEY, R. B. (1997) Recovery of useful chemicals from local salt bitterns, *J. Appl. Sci. Tech.* **2** (1&2), 77-84.

MENSAH, B. & BAYITSE, R. (2005) Quality Assessment of Locally Produced Common Salt (Sodium Chloride). *A Paper presented at CSIR-IIR Research Output Review Seminar, 11-13 October, 2005.*

OWUSU, A. A. (1971) *Sodium Chloride: Production, Quality and Possible Uses of Common Salt in Ghana*. Technical Report, CSIR-Industrial Research Institute-Ghana.

PANDEY, G. N. (1997) *A Textbook of Chemical Technology*, vol. 1. Vickas Publishing House PVT Ltd.

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