

# Brine Resource Management through Wireless Sensor Network in Solar Evaporation Type Salt Manufacturing Process

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**Abstract**—As a part of the embedded system development, Wireless Sensor Network (WSN) is an emerging technology in many industrial applications. This paper is aimed to apply the effectiveness of this technology in solar evaporation type salt manufacturing industry for brine resource management. Brine is the main resource for salt manufacturing. The brine can be obtained from sea, lake or from inland source. Where the brine is obtained from inland source, the initial salinity available is higher than other sources. Energy is consumed to extract brine from any kind of source. The consumption of energy/fuel is directly proportionate to the quantity of brine. The additional extraction of brine than required level by the industrial unit leads to wastage of energy and results in increasing land pollution. The less amount of brine than required level leads to quality degradation and production loss. So the brine resource management is very important in salt production. Traditionally manual approach is applied for brine flow management in the solar salt industries till today. The application of wireless sensor technology leads to reduced human intervenes as well as improved resource management by optimizing salt recovery per liter of brine.

**Keywords**—*Brine Resource management; Solar Evaporation; Wireless Sensor Network*

## I. INTRODUCTION

In the Little Runn of Kutch (LRK) of Gujarat state, the land and water are saline, which is not suitable for the agriculture. The area is one of the driest in the state with average annual rainfall ranging between 10 inches to 16 inches. The traditional salt manufacturing process is technologically semi-developed and labor intensive [1]. In 2013-2014, the Indian salt industries have produced 230.19 lakh tonnes of salt, in which contribution of private sectors is 91% [2]. There are so many small scale private salt manufacturing units distributed across the coastal area of the LRK in Gujarat. A typical lay-out of one of these units is considered as our study field. The salinity of inland brine available from the well for this kind of site ranging between 12 BC and 19 BC (BC is Baume Centigrade; in local language it is called “Degree”). Number of condensers required for

solar evaporation is depends on the initial salinity of the brine source. The lower salinity demands more evaporation area and hence number of evaporative condensers is large.

The manufacturing unit of the study field has total 6 condensers and 1 crystallizer pan. The brine supply is kept at somewhat upper level in height than crystallizer pan, so that brine flows gravitationally from successive condensers. Brine flow between two successive condensers is controlled manually by increasing or decreasing inter-condenser channel-width. The traditional channel is created by bamboo and mud of clay. Natural solar evaporation is the main factor to increase the salinity of the brine [3]. As salinity of brine increases, evaporation decreases [4]. Evaporation of the water from brine contributes to increase the salinity of the brine, which can be considered for estimation of salinity gradient.

## II. SYSTEM DESCRIPTION

### A. Salinity Gradient

Salinity gradient is defined as change in salinity with linear distance [5]. In case of ocean chemistry the distance is considered in vertical direction. While in case of salt manufacturing, salinity increases with horizontal distance moving from the source of brine to the crystallizer pan. Increasing salinity gradient has been developed throughout the series of condensers of the salt works with a simultaneous and continuous reduction of the volume of the brine, which initially having low concentration and entered via channel in the first condenser.

Linear salinity gradient is created manually by controlling of inter-condenser channel. As salinity of the brine increased at pre-decided level through evaporation, then that more saline brine is allowed to flow in next condenser. After every successive condenser approximately, 1 BC salinity increases in summer season. This sequence is kept continue till the crystallizer pan. When salinity reaches near about saturation then and only then brine is allowed in the crystallizer pans. Simultaneously in order to obtain optimum evaporation benefit, the brine level is maintained at few (approximate 10) cm in each condenser. Considering these the pump installed at brine source must be operated. Numbers of condensers seasonally vary with evaporation rate. In winter season

number of condensers is more than summer season. From above description, brine, fuel, human power, land, etc. are identified as major affecting resources, in order to manage salinity gradient and for the improvement of salt production through solar evaporation based salt manufacturing process.

**B. The Evaporation Rate Measurement System**

As all the solar evaporation type salt manufacturing units do not have nearby meteorological stations, demand of in-situ parameter acquisition has been increased. Day by day new methods are invented for the determination of parameters affecting the evaporation process [6]. Some parameter shows site specific variability (SSV). For site specific resource management (SSRM), collection of parameters showing SSV is the need of hour.

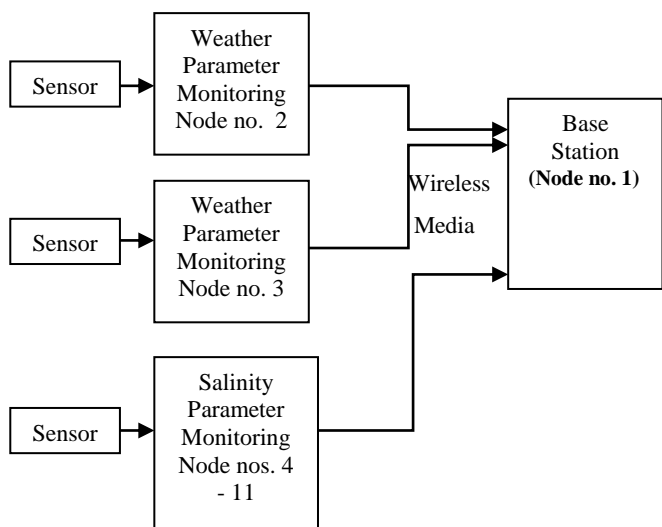


Figure 1: Conceptual block diagram of the developed distributed embedded system

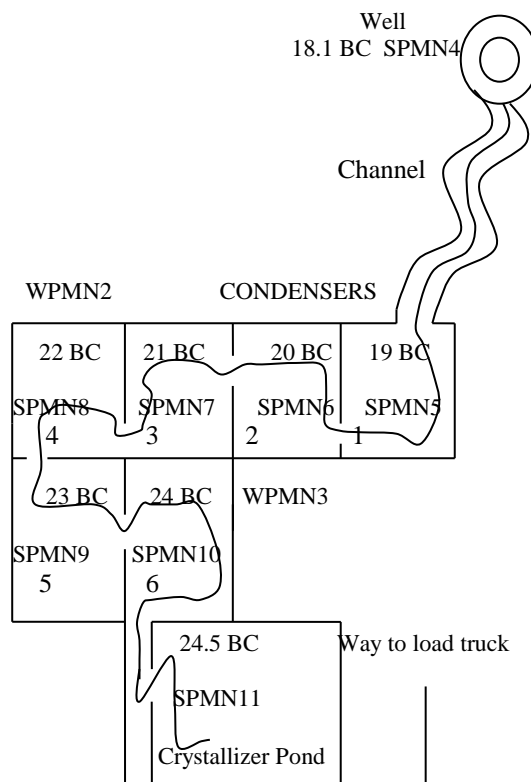
The system consists of a base station, two different types of weather parameter nodes and eight salinity parameter monitoring nodes. Every node have configured with various sensors [7]. The base station receives sensed data from nodes via wireless media. The processing of the data takes place at the base station. Base station also has display facility for manual actuator operations. The designed system is used to measure the evaporation rate of brine and proved helpful to operate different actuators manually according to the measured evaporation rate.

The data of evaporation parameters like maximum and minimum temperature, concentration of sodium chloride in brine, elevation of the site above mean sea level, Number of the day of the year, latitude of the location, actual duration of the sunshine hours of the day, albedo of the evaporating surface, average relative humidity and wind speed are put in to Penman’s equation [8] [9] based MATLAB simulation [10] and evaporation rate in mm/day of every day from 2<sup>nd</sup> April 2018 to 16<sup>th</sup> April 2018 is obtained for each condenser.

Determination of brine conductivity and brine temperature is useful to measure the salinity of brine [11]. Salinity of each condenser is continuously monitored using above mentioned wireless sensor network.

**III. EXPERIMENTAL SET-UP**

In weather parameter monitoring nodes, first node (node no.2) consists LPC2148 microcontroller based integrated development environment with air temperature and humidity sensors. The second one (node no.3) consists of solar light intensity and wind speed sensors configured with ATmega 328/P microcontroller based integrated development environment. The third part shows a salinity parameter monitoring nodes. These nodes consist of brine conductivity and brine temperature sensors embedded with ATmega 328/P microcontroller based integrated development environment. Condenser-wise one salinity parameter monitoring node (SPMN) is installed. Two additional SPMNs one at brine supply source and one at crystallizer pan are installed. Every node has a zigbee module based wireless communication link to send the data to the common base station.



- SPMN: Salinity parameter Monitoring Node
- WPMN: Weather Parameter Monitoring Node

Figure 2: Experimental site layout and node deployment

Figure 2 shows site lay out used for experimental purpose and node deployment positions. The brine available at the source is with salinity of 18.1 BC. Condenser 1 is supplied this

brine through channel. Supply is controlled by varying ON and OFF time durations of pump installed at the inland supply source point. Brine supply is measured in integer cubic meters. Finally, salt recovery in grams per liter of brine has been calculated and it is compared with the recovery of the traditional salt manufacturing process.

In the traditional solar salt manufacturing system, inter-condenser actuators are not operated according to brine evaporation and brine consumption but manual experience based approach is applied for the actuator control. Where, in above research study; researchers are allowed to operate brine source actuator as well as inter-condenser actuators according to system's measurements. The result is shown in the tables given below.

Timely brine supply and transfer from one condenser to next condenser when the proper increment of salinity achieved is equally important for optimum growth and required quality yield of sodium chloride crystals. If sharp control over successive condenser not followed and a large volume of brine is transferred through one condenser to another and from last condenser to crystallizer pond, temperature and salinity of condensers and pond may be disturbed this abrupt change may result in lower grade salt production. Short supply of the brine may cause production loss also. If excessive brine is supplied, then there is a chance of wastage of brine.

IV. SYNCHRONIZATION OF BRINE SUPPLY WITH EVAPORATION RATE AND SEEPAGE

TABLE I. CONDENSER WIDE BRINE FLOW MANAGEMENT

Brine Flow Management (Considering Evaporation rate and seepage):						
Apr-2018	Condenser-1			Condenser-2		
	E-rate	BLRR	TWC	E-rate	BLRR	TWC
	mm/day	mm/day	m <sup>3</sup>	mm/day	mm/day	m <sup>3</sup>
2	6.77	6.78	5.88	6.65	6.66	6.44
3	6.81	6.82	5.91	6.68	6.69	6.47
4	6.86	6.87	5.96	6.73	6.74	6.52
5	6.91	6.92	6.00	6.78	6.79	6.56
6	6.93	6.94	6.02	6.80	6.81	6.59
7	6.97	6.98	6.05	6.84	6.85	6.62
8	7.00	7.01	6.08	6.87	6.88	6.65
9	7.05	7.06	6.12	6.92	6.93	6.69
10	7.08	7.09	6.15	6.95	6.96	6.73
11	7.12	7.13	6.18	6.99	7.00	6.76
12	7.16	7.17	6.22	7.03	7.04	6.80
13	7.20	7.21	6.25	7.07	7.08	6.84
14	7.25	7.26	6.29	7.12	7.13	6.89
15	7.30	7.31	6.34	7.17	7.18	6.94
16	7.34	7.35	6.37	7.21	7.22	6.97

TABLE II. CONDENSER WIDE BRINE FLOW MANAGEMENT

Brine Flow Management (Considering Evaporation rate):						
Apr-2018	Condenser-3		Condenser-4&5		Condenser-6&cp	
	E-rate	TWC	E-rate	TWC	E-rate	TWC
	mm/day	m <sup>3</sup>	mm/day	m <sup>3</sup>	mm/day	m <sup>3</sup>
2	6.52	6.52	6.33	12.66	5.65	22.59
3	6.56	6.56	6.37	12.73	5.68	22.71
4	6.61	6.61	6.41	12.83	5.72	22.88
5	6.65	6.65	6.46	12.92	5.76	23.04
6	6.68	6.68	6.48	12.96	5.78	23.12
7	6.72	6.72	6.52	13.03	5.81	23.25
8	6.74	6.74	6.54	13.09	5.84	23.34
9	6.79	6.79	6.59	13.17	5.87	23.50
10	6.82	6.82	6.62	13.24	5.91	23.62
11	6.86	6.86	6.66	13.31	5.93	23.74
12	6.90	6.90	6.69	13.39	5.97	23.88
13	6.94	6.94	6.73	13.47	6.01	24.02
14	6.98	6.98	6.78	13.55	6.04	24.18
15	7.03	7.03	6.83	13.65	6.09	24.35
16	7.07	7.07	6.86	13.72	6.12	24.48

Apr = April  
 E-rate = Evaporation rate  
 cp = crystallizer pans

BLRR = Brine Level Reduction Rate = E-rate + Seepage loss

(For condenser 1& 2 Seepage loss =0.01 and for condenser 3,4,5,6 and crystallizer pan considered seepage loss is nil because of salt deposition at the bottom of condensers. In higher order condensers, a layer of salt deposited at the bottom reduces the seepage considerably.).

TWC = Total Water consumed = BLRR \* Area in Square Meters

(Area of condenser 1 is 867 sq. meters, area of condenser 2 is 967 sq. meters, area of condenser 3 is 1000 sq. meters, area of condenser 4 and 5 is 2000 sq. meters and total area of condenser 6 and crystallizer pan is 4000 sq. meters.)

The amount of water utilized through daily evaporation and seepage must be supplied for respective condenser to maintain the brine level in the condenser. For this purpose, daily condenser-wise evaporation and seepage are shown in the table 1. From condenser 3 onwards seepage is negligible, that's why the utilized water is calculated through only evaporation as shown in table 2. Table 3 describes daily total brine supply from the brine source. It compares brine supply for WSN system guided salt manufacturing process with traditional process.

TABLE III. TOTAL BRINE SUPPLY FROM THE SOURCE

Apr-18	TCWV	ESC	EBSV	ABSV	ASP	TBSV	TSP
Day	in1000L	in1000Kg	in1000L	in1000L	in1000Kg	in1000L	in1000Kg
2	54.09	12.38	66.47	66.00	11.92	70.00	10.97
3	54.38	12.45	66.83	67.00	12.28	71.00	10.26
4	54.79	12.54	67.33	67.00	12.22	71.00	10.99
5	55.17	12.63	67.79	68.00	12.43	72.00	10.44
6	55.36	12.67	68.02	68.00	12.64	72.00	10.78
7	55.67	12.74	68.41	68.00	12.35	73.00	10.11
8	55.90	12.79	68.70	69.00	12.50	73.00	10.53
9	56.27	12.88	69.14	69.00	12.75	73.00	11.18
10	56.57	12.95	69.52	70.00	12.50	73.00	11.74
11	56.85	13.01	69.86	70.00	12.87	74.00	11.00
12	57.19	13.09	70.28	70.00	12.83	74.00	11.61
13	57.53	13.17	70.69	71.00	12.87	74.00	12.22
14	57.89	13.25	71.14	71.00	13.12	75.00	11.65
15	58.32	13.35	71.66	72.00	13.02	75.00	12.41
16	58.62	13.42	72.04	72.00	13.39	75.00	12.96
Total:	193.30	193.30	1037.88	1038.00	189.69	1095.00	168.86

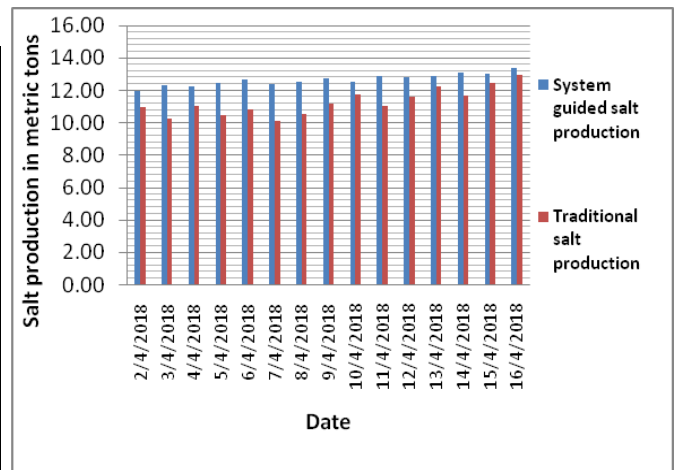


Figure 3: Date wise system guided salt production and traditional salt production

TABLE IV. SALT RECOVERY FROM THE BRINE

Salt recovery gram per liter of brine			Salt recovery in percentage	
Standard expected salt recovery	Traditional system salt recovery	WSN system guided salt recovery	Percentage of traditional system salt recovery compared with standard	Percentage of WSN guided system salt recovery compared with standard
216.7	154.2	182.7	71.16%	84.31%

From above table it is summarized the difference between traditional salt recovery and system guided actual salt recovery per liter of brine is larger where the brine supply is not synchronized with real-time evaporation rate and seepage.

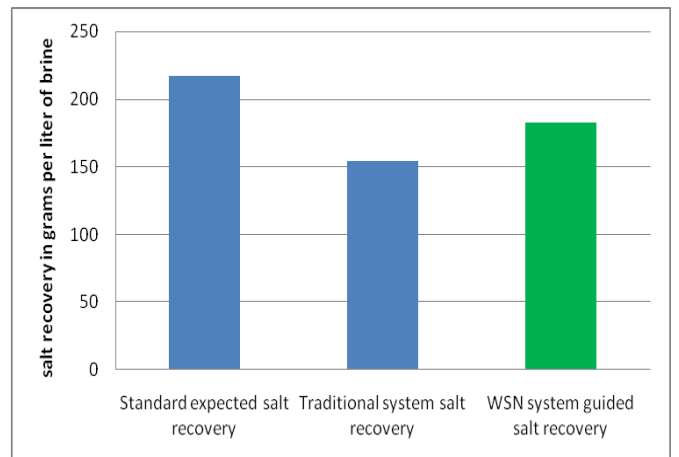


Figure 4: chart showing salt recovery per liter of brine.

V. CONCLUSION

The brine supply is more accurately utilized in system guided production process. This is due to actuator operation synchronization with the evaporation rate and seepage of the brine. The Percentage of traditional system salt recovery compared with standard expected maximum

TCWV = Total Consumed Water Volume from brine (condenser 1 to crystallizer pans = Sum of all TWCs of table 1 and table 2)

ESC = Expected Salt Content of the supplied brine (can be calculated from the initial salinity of the brine)

$$= (((TCWV * 216.7 / 1000) * 1.143) / 1000) * 924$$

Initial salinity of the brine = 18.1 BC at 15.5 °C which corresponds 216.7 gram/liter NaCl, 1.143 is initial specific gravity and 924gm Water content of the brine

BC = Baume centigrade

EBSV = Expected Brine Supply Volume

ABSV = Actual Brine Supplied Volume

ASP = Actual Salt Production after system guidance

TBSV = Traditional Brine Supply Volume

TSP = Traditional Salt Production

In nearby unit having initial and environmental same conditions, the traditional experience based manually decided brine supply system; the supplied brine volume values are found different (little more) than they decided by the system guidance in this research study. Salt worker’s non-technical skill and lack of technological approach may be reason for this difference. According to table no. 3, in the traditional system for the specified duration (fortnight) total 1,095 kilo liters of brine has been supplied and 168.86 metric tons salt recovered. Calculating salt recovery per liter of brine is results in 154.2 gram per liter.

salt recovery is 71.16%, whereas implementation of WSN based system has improved the salt recovery up to 81.31%, which shows a net increment of 13.15% due to actuator control according WSN system guidance. Thus brine resources and hence fuel resources can be managed effectively when the brine is supplied according to the evaporation and seepage. Wireless sensor network of the distributed embedded system has proved its effectiveness in solar salt production.

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