

Upgrading of Solar Salt — Quality vis-a-vis Mechanical Equipment

H.M. Gohil

Tata Chemicals Limited, Mithapur, Gujarat State, India

ABSTRACT

Common salt as produced by solar evaporation of seawater or inland brine is often unsuitable for many applications. Common salt, sodium chloride, is an important raw material for heavy chemical industries such as caustic soda and soda ash. Particularly for industries, the quality of the salt is important. The quality of salt is improved by washing out the impurities. For washing of salt, different types of equipment and processes are being developed. All these types of washing techniques can produce washed salt which conforms to ISI Grade II. To obtain higher purity the feed salt needs grinding, contact with brine/seawater or raw water followed by separation of the washed liquor. Different mechanical equipment results in different quantities of salt losses and proper selection of the equipment is necessary in order to meet particular requirements.

INTRODUCTION

This paper describes various mechanical equipment currently employed for beneficiation of solar salt, the relation between equipment and quality of washed salt, and also other experimental data.

There are two main types of impurity found in common salt: (i) superficial impurities, and (ii) trapped impurities. For removal of impurities (Mohiuddin et al., 1965) various types of equipment and processes are being developed, namely:

1. Disperse Washing Column
2. Screw Conveyor Washing
3. Hydro Cyclone Washing
4. Single Classifier Washing
5. Double Classifier Washing
6. Mixing Tank with Classifier Washing
7. Rotary Drum with Classifier Washing
8. Hydrocyclone Classifier Washing
9. Vibrator Screen Washing
10. SELEX (Double Column Cyclone) Method
11. Double Screw Washing with Mixing Tank
12. Split Plane and Raker for Crystallizer.

Salt produced in salt works is a comparatively low cost commodity (Gohil, 1977). So far the reason of economy of salt produced has to carefully consider and optimise various processes available for up-gradation of solar salt in order to make the salt suitable for various use and to improve the quality of the product at lowest possible cost. From view point of heavy chemicals industry which utilise salt in the

form of pure saturated brine, (Japanese Soda Industrial Association, pers. commun., 1962) where the raw brine is purified by precipitation followed by settling and filtration. The cost of treatment and to a certain extent the size of treatment plants depends on the quality of raw salt. If the quality of raw salt is good, the treatment required will be less. To dispose of the salt as produced by salt works, it is necessary to wash the same by mechanical washing. Some experiments were also carried out in salt works to obtain good quality salt by heap washing with fresh seawater.

Common salt produced (Majithia, et al., 1984) by solar evaporation of seawater in India contains about 96-98% of sodium chloride and 2-4% of impurities present as sulphates and chloride of calcium, magnesium along with insoluble matter. There are two type of impurities: superficial impurities and trapped impurities. Superficial impurities can be removed by washing the salt with a saturated salt solution or seawater whereas for trapped impurities, crystals are passed through the crusher followed by washing with salt solution or seawater.

METHODS, TECHNIQUES AND MATERIALS

1. Disperse washing column

The disperse washing column (Fig. 1) consists of a cylindrical column with a conical bottom in which salt is fed to the top from a belt conveyer via a crusher and brine is allowed to enter from the bot-

tom. The crusher is intended to provide salt particles having a size of 8 BSS Mesh (2.36 mm).

The impurities are carried along with the overflow which is collected in a settling tank. The salt particles, being heavier than brine, settle at the bottom after washing and are allowed to fall on the vibrator screen (as 40% slurry) from where liquor drains into the settling tank and the washed salt gets carried on a belt conveyor to stacking. The liquor can be recycled after settling until it gets saturated with respect to magnesium. The results are given in Table 1.

2. Screw conveyor washing

The crushed salt (Mohiuddin et al., 1965) having a size of 8 BSS (2.36 mm) is fed to the screw conveyor where brine is being sprayed; from here the salt is allowed to fall into the second screw conveyor in which brine is maintained in such a way that the salt particles remain in intimate contact for 40 s with brine solution for better washing (Woodhill, 1961). The washed salt along with discharge brine is allowed to fall on a vibrating screen from where the salt is carried by a portable belt conveyor to stacking (Fig. 1). The results are tabulated in Table 1.

3. Hydrocyclone washing

This is a continuous type of washing system in which the crushed salt is mixed with brine solution in a mixing tank from where the salt slurry is pumped into the hydrocyclone (Gohil, 1979). The salt particles being heavier settle in the hydrocyclone and the impurities in the form of solution overflow from the hydrocyclone and are collected in the settling tank. The underflow containing washed salt is allowed to fall on the vibrator from where the salt is carried by portable conveyor belt to stacking (Fig. 1). The experimental data are tabulated in Table 1.

4. Single classifier washing:

The crushed salt (Febevre Report, 1962) is fed to the spiral classifier (Fig. 1) in which it remains in intimate contact with brine solution for about one minute. An additional spray is also provided from which either brine or seawater can be sprayed. The washed salt is directly stacked from the classifier. The results are tabulated in Table 1.

5. Double classifier washing

This comprises two spiral classifiers (Fig. 1). The salt is fed to the first spiral classifier in the same manner as described above for single classifier washing. The salt slurry is discharged to the second spiral classifier in order to provide double-effect washing. The washed salt is directly stacked. The results are tabulated in Table 1.

6. Mixing tank with classifier washing

The crushed salt is fed to the mixing tank in which it is mixed with brine solution from where the resultant salt slurry is pumped to the spiral classifier and salt is allowed to remain in contact with the brine solution (Fig. 1) (Febevre Report, 1962) for about a minute and finally discharged to stacking directly. The results are tabulated in Table 1.

7. Rotary drum with classifier washing

The crushed salt is fed to a rotary washing drum (Fig. 2) operated at 9 rpm where salt particles are allowed to be scrubbed in brine solution. The salt slurry is led to the spiral classifier in which salt is being washed and discharged to stacking. The results are tabulated in Table 1.

8. Hydrocyclone classifier washing

The unwashed salt is fed to the mixing tank from where the salt slurry is pumped to the hydrocyclone in which the heavier salt particles settle; it is then led to the spiral classifier where the salt is finally washed and discharged to stacking (Fig. 2). The results are tabulated in Table 1.

9. Vibrator screen washing

The salt is conveyed to the vibrating screen after crushing where seawater or brine is sprayed (Fig. 2). The washed salt is then conveyed by belt conveyor to stacking. The results are tabulated in Table 1.

10. Selex (double column cyclone) method

The salt is fed to a washing column (Woodhill, 1961) from where the salt slurry is pumped to a hydrocyclone in which salt particles, being heavier, settle; it is then led to a second washing column from where the salt slurry is collected in the decanter and the resultant salt is carried after centrifuging via conveyor belt to stacking (Fig. 2). The results are tabulated in Table 1.

11. Double screw washing with mixing tank

The crushed unwashed salt is fed to the screw feeder which contains two screens moving in opposite directions with a spray of brine at the top (Fig. 2). The slurry is led to the mixing tank from where it is pumped to the vibrating screen where brine is sprayed and the washed salt is conveyed via belt conveyor to stacking. The results are tabulated in Table 1.

12. Raker and split plane unit

This unit is useful in the sense that the salt harvested initially is split to get a plane bed and bittern is drained; the fresh brine is allowed to evaporate for salt precipitation over the split plane bed,

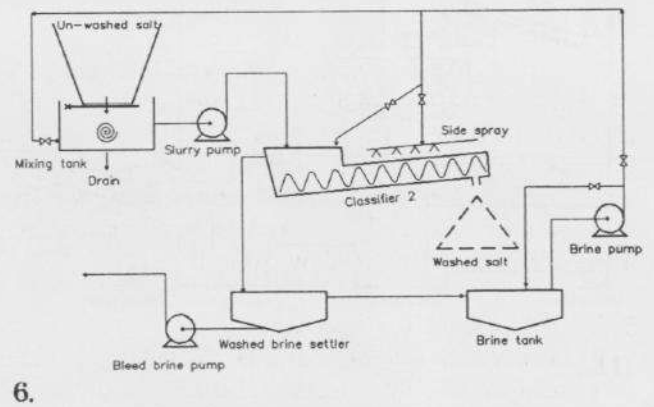
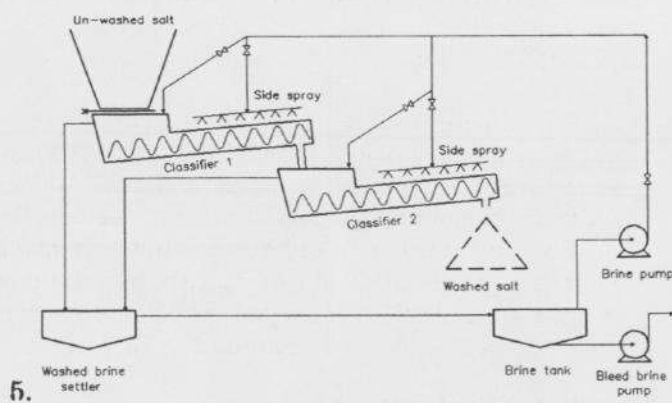
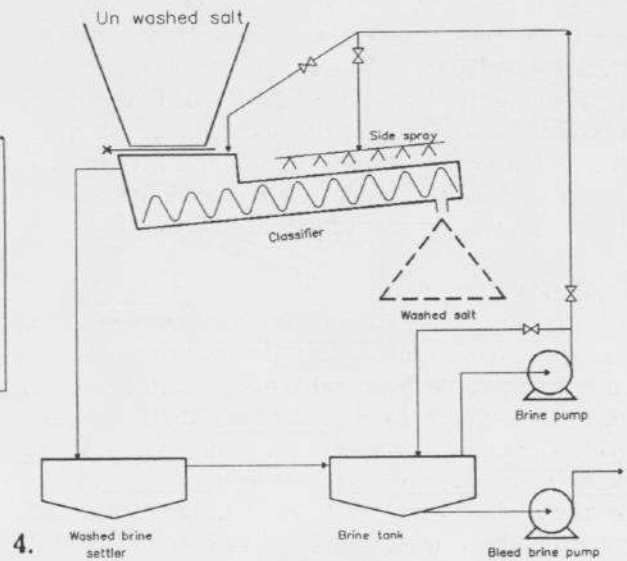
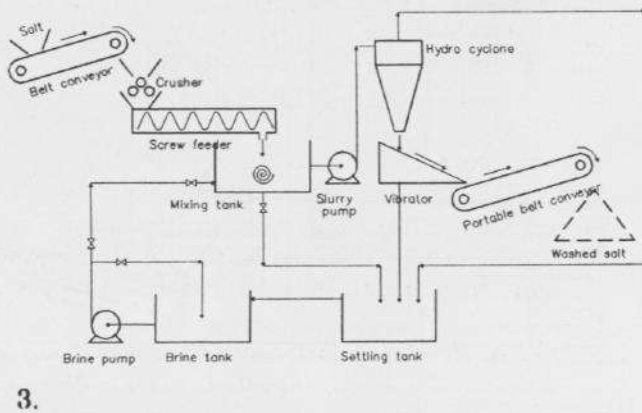
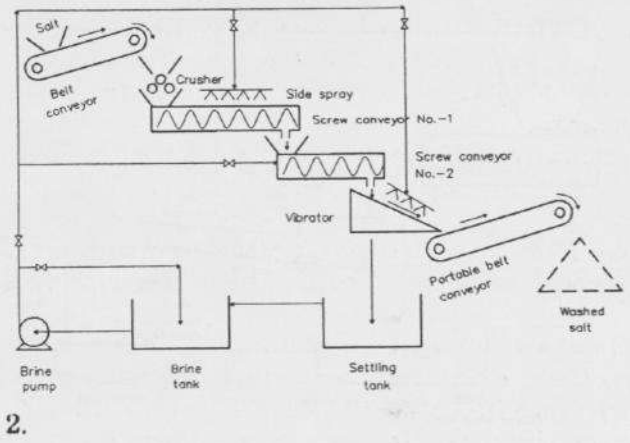
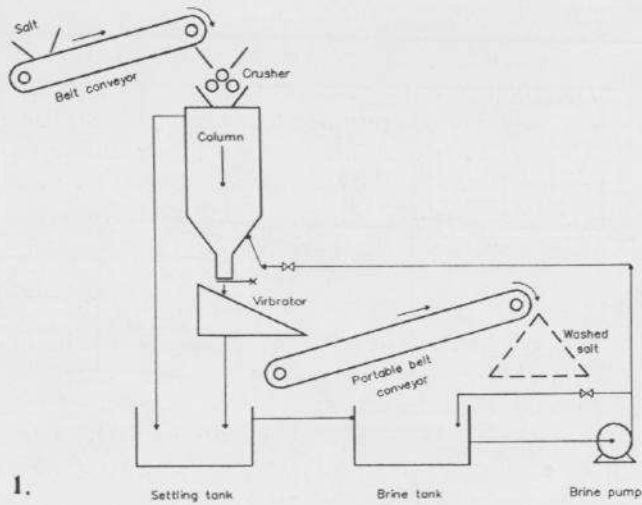
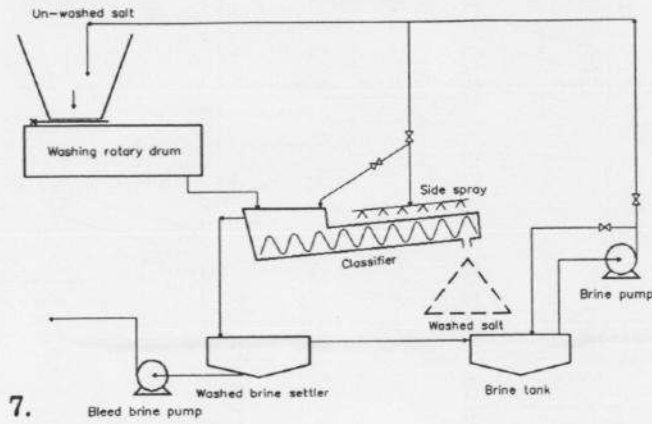
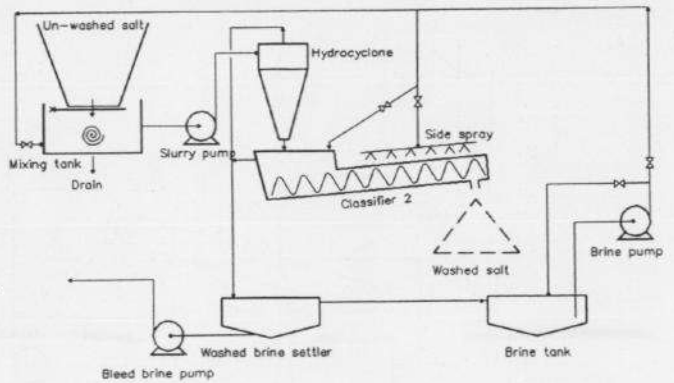


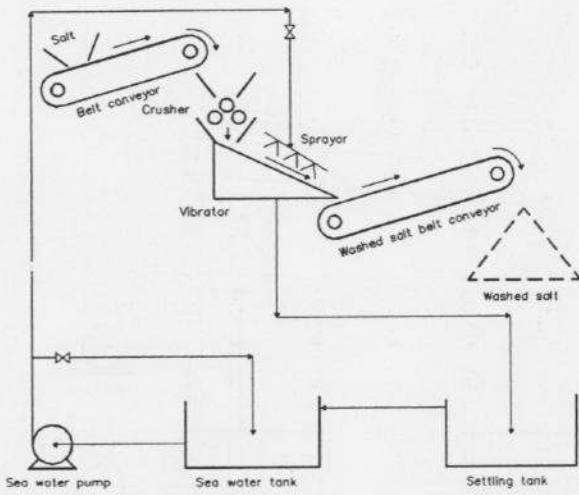
Fig. 1. 1. Disperse washing column. 2. Screw conveyor washing. 3. Hydrocyclone washing. 4. Single classifier washing. 5. Double classified washing. 6. Mixing tank with classifier washing.



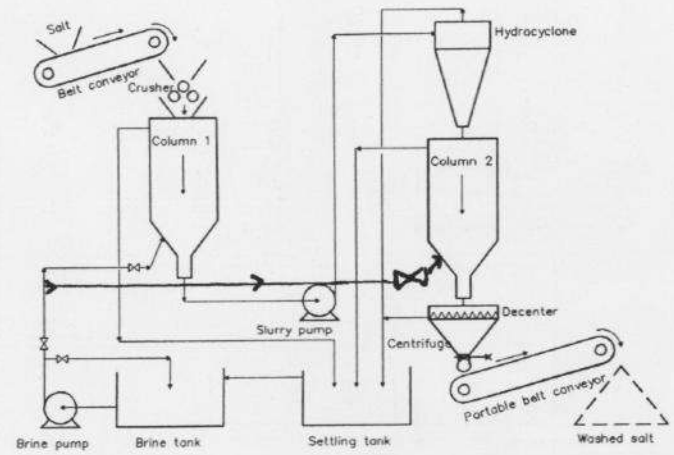
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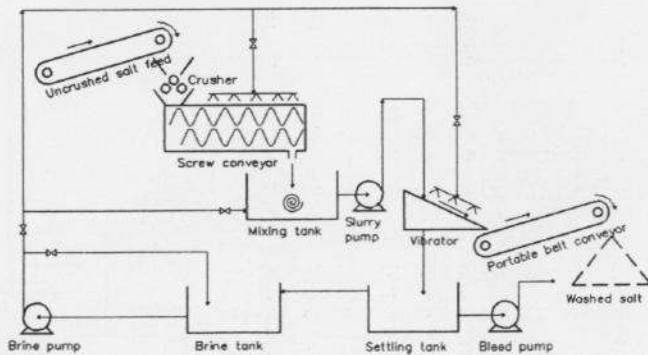
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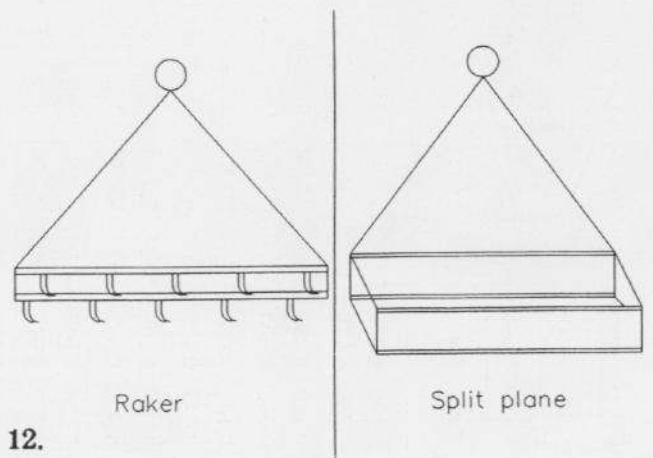
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Fig. 2. 7. Rotary drum with classifier washing. 8. Hydrocyclone classifier washing. 9. Vibrator screen washing. 10. Selex (double column cyclone) method. 11. Double screw washing with mixing tank. 12. Split plane and raker for crystallizer.

TABLE 1
Results of washing experiments

Test no.	Particulars of the salt	Chemical analysis				Removal efficiency				Weight recovery			Brine recovery			Side spray S.G./°Bé	Salt feed (t/min)	Brine feed (l/min)
		Ca ²⁺	Mg ²⁺	SO ₄ ²⁻	Insol.	NaCl	Ca (%)	Mg (%)	SO ₄	Insol.	Input (%)	Output (%)	Loss (%)	Input (%)	Output (%)			
1	Unwashed	0.100	0.330	0.640	0.110	97.10												
	Washed	0.050	0.060	0.230	0.070	99.44	50.00	82.00	64.00	36.00	100.00	90.00	10.00	100.00	98.00	2.00	Not used	0.05
2	Unwashed	0.160	0.410	0.890	0.120	97.30										1.1800		
	Washed	0.090	0.050	0.220	0.060	98.45	44.00	88.00	75.00	50.00	100.00	85.00	15.00	100.00	93.00	7.00	22°Bé	0.10
3	Unwashed	0.160	0.600	0.750	0.120	97.15												
	Washed	0.040	0.170	0.340	0.060	98.88	68.00	55.00	44.00	50.00	100.00	93.00	7.00	100.00	93.00	7.00	Not used	0.10
4	Unwashed	0.091	0.088	0.324	0.287	98.34										1.2000		
	Washed	0.032	0.047	0.113	0.087	99.45	64.80	46.60	65.10	69.70	100.00	98.60	1.40	100.00	98.50	1.50	24°Bé	0.06
5	Unwashed	0.028	0.049	0.097	0.079	99.45										1.2000		
	Washed	0.020	0.045	0.084	0.063	99.55	28.60	8.20	13.40	20.20	100.00	99.20	0.80	100.00	95.30	4.70	24°Bé	0.06
6	Unwashed	0.091	0.088	0.324	0.287	98.34										1.2000		
	Washed	0.028	0.047	0.091	0.086	99.51	70.00	48.00	73.00	71.00	100.00	97.10	2.90	100.00	96.10	3.90	24°Bé	0.06
7	Unwashed	0.091	0.088	0.324	0.287	98.34										1.2000		
	Washed	0.030	0.048	0.099	0.081	99.50	67.00	45.00	69.00	72.00	100.00	97.80	2.20	100.00	99.60	0.40	24°Bé	0.06
8	Unwashed	0.091	0.088	0.324	0.287	98.34										1.1900		
	Washed	0.029	0.038	0.076	0.106	99.45	68.00	56.80	76.50	63.00	100.00	93.50	6.50	100.00	94.40	5.60	24°Bé	0.06
9	Unwashed	0.260	0.300	0.600	0.650	96.44										1.1300		
	Washed	0.100	0.100	0.300	0.200	98.70	38.00	67.00	50.00	65.00	100.00	89.50	10.50	100.00	90.00	10.00	16°Bé	0.25
10	Unwashed	0.100	0.200	0.324	0.287	98.34												
	Washed	0.032	0.047	0.113	0.087	99.49	64.80	76.50	65.10	69.70	100.00	98.60	1.40	100.00	98.50	1.50	Not used	0.08
11	Unwashed	0.100	0.085	0.299	0.289	98.34										1.200		
	Washed	0.036	0.043	0.114	0.088	99.25	64.00	49.40	61.90	69.60	100.00	92.80	7.20	100.00	99.00	1.00	24°Bé	0.15

thus impurities from the ground are avoided (Fig. 2). Finally, the salt is raked and, by so doing salt particles of a uniform size and with fewer entrapped impurities can be obtained which subsequently reduces the washing load at the later stage. The results are tabulated in Table 2.

Another experiment carried out involved putting a fresh saturated brine solution having 25°Bé in the crystallizer before harvesting salt followed by raking again, as a result of which the quality of the raked salt was further improved. The results are given in Table 3.

RESULTS AND DISCUSSION

Test 1

The efficiencies of removal of calcium, magnesium, sulphate and insolubles were found to be 50, 82, 64 and 36%, respectively, and the salt loss was 10%, with increase in NaCl content from 97.1 to 99.44%. While performing the test it was observed that material got jammed in the column, resulting in frequent forced stoppages.

Test 2

The efficiencies of removal of calcium, magnesium, sulphate and insolubles were found to be 44, 88, 75, and 50%, respectively, and the salt loss was 10%, while increasing NaCl content was from 97.30 to 98.4%. This method is power-consuming in comparison with other methods. There is a better washing efficiency due to two-stage washing and low side spray brine density, but the loss of salt is high.

Test 3

The efficiencies of removal of calcium, magnesium, sulphate and insolubles were found to be 68, 55, 44, and 50%, respectively, and the salt loss was 7%, with increase in NaCl content from 97.15 to 98.88%. Side spray was not used in this method; the results achieved are not satisfactory for washing efficiency and salt losses. Side spray can be used for better results but it can increase salt losses.

Test 4

The efficiencies of removal of calcium, magnesium, sulphate and insolubles were found to be 64.8, 46.6, 65.1, and 69.7%, respectively, and the salt loss was 1.4%, with increase in NaCl content from 98.34 to 99.45%. Low power consumption is the major aspect of this process and minimum salt loss compared to tests number 1, 2 and 3. 24°Bé brine was used for side spray. Implementation on a large-scale can be carried out.

TABLE 2

Sieve analysis

ASTMM	mm	Raked salt (%)	Unraked salt (%)
+3/4"	19.00	Nil	Nil
+1/2"	12.5	Nil	0.44
+3/8"	9.5	1.01	1.97
+No.5	4.75	17.05	24.42
+No.10	2.36	21.5	25.86
+No.35	500 mm IC	22.27	46.31
-No.35	500 mm IC	38.17	1.01

TABLE 3

Chemical analysis of raked, unraked salt and washed raked salt

	Unraked salt (%)	Raked salt (%)	Raked salt washed with fresh brine (%)
Ca ²⁺	0.136	0.104	0.108
Mg ²⁺	0.254	0.11	0.104
SO ₄ ²⁻	0.629	0.358	0.358
Cl ⁻	57.26	59.04	59.39
K ⁺	0.00	0.00	0.00
CaSO ₄	0.353	0.217	0.244
MgSO ₄	0.477	0.256	0.232
MgCl ₂	0.583	0.234	0.224
NaCl	93.66	97.01	97.60
KCl	0.00	0.00	0.00
Insol.	0.9	0.22	0.05
Moisture	4.8	1.959	1.54

Test 5

The efficiencies of removal of calcium, magnesium, sulphate and insolubles were found to be 28.6, 8.2, 13.4, and 20.2%, respectively, and the salt loss was 0.8%, with increase in NaCl content from 99.45 to 99.55%. This experiment was carried out only for checking second stage washing. This method is power consuming.

Test 6

The efficiencies of removal of calcium, magnesium, sulphate and insolubles were found to be 70, 48, 73, and 71%, respectively, and the salt loss was 2.9%, with increase in NaCl contents from 98.34 to 99.51%. Salt and brine losses are higher. Side spray was used. Washing efficiency is considerably high.

Test 7

The efficiencies of removal of calcium, magnesium, sulphate and insolubles were found to be 67, 45, 69, and 72%, respectively, and the salt loss was 2.2%, with increase in NaCl content 98.34 to 99.50%. 23°Bé brine was used as side spray. Due to high scrubbing, salt losses are higher and brine losses are also higher.

Test 8

The efficiencies of removal of calcium, magnesium, sulphate and insolubles were found to be 68, 56.8, 76.5, and 63%, respectively, and the salt loss was 6.5%, with increase in NaCl content from 98.34 to 99.45%. This is a highly salt- and brine-loss oriented method due to reduction in the particle size of salt.

Test 9

The efficiencies of removal of calcium, magnesium, sulphate and insolubles were found to be 38, 67, 50, and 65%, respectively, and the salt loss was 10.50%, with increase in NaCl content from 98.70 to 96.44%. This is a highly salt- and brine-loss oriented method due to reduction in the particle size of salt.

Test 10

The efficiencies of removal of calcium, magnesium, sulphate and insolubles were found to be 64.8, 76.5, 65.1, and 69.7%, respectively, and the salt loss was 1.4%, with increase in NaCl content from 98.34 to 99.49%. Despite not using side spray, the results achieved are considerably attractive with bare minimum loss of brine and salt with low power consumption. This is better in all respects for a large plant.

Test 11

The efficiencies of removal of calcium magnesium, sulphate and insolubles were found to be 64.0, 49.4, 61.9, and 69.6%, respectively, and the salt loss was 7.2%, with increase in NaCl content from 98.39 to 99.25%. This is a power-consuming method. Salt losses rate quite highly, but brine losses are low as 24°Bé brine was used for side spray.

Test 12

As can be seen from the result obtained in Table 2, raked salt is able to produce a particle size smaller than +35 ASTM mesh size which will also result in better washing efficiency. Due to the smaller size of raked salt, trapped impurities are reduced and bonded moisture is also reduced. This will result in a better quality of salt with respect to higher chloride content as shown in Table 3.

Results obtained by washing raked salt with fresh

brine are similar to raked salt which indicates a better quality of salt obtained by raking. If this salt is allowed to be rain washed (Bhatt et al., 1974) the quality will be further improved.

CONCLUSIONS

In the above test the percentage of removal of calcium, magnesium, and insolubles were found to vary from 28.5 to 70.00%, 10 to 80%, 13 to 75% and 20 to 70%, respectively. The purity of feed salt has increased from 97.30 to 99.45% of NaCl.

Regarding the efficiency of washing, in any washing process the superficial impurities can be removed by washing. Trapped impurities are not removed by washing but by grinding the salt to a smaller size and removing trapped impurities by washing.

Each of the above methods for salt upgrading has its own advantages and disadvantages. Methods 4 and 10 have minimum salt and brine loss, particularly method 10 in which the brine requirement is the bare minimum. It is therefore better to adopt these two methods on a large scale after considering for the capital cost and operating cost.

In tests 2 and 9, the salt loss can be reduced further to about 2–8% by using a side spray of higher density (24°Bé). However, it is always advisable to improve salt quality at the crystalliser itself by using split plane and raking. Raked salt followed by methods 4 or 10 will give the best quality salt ever available.

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