PROCESSING OF SALT FOR CHEMICAL AND HUMAN CONSUMPTION

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The presence of impurities in salt has serious economic and environmental consequences. Impurities increase the cost of brine treatment in chloralkali plants, magnify the problems of contaminated effluent disposal and necessitate costly refining of salt for human consumption. The hydromechanical salt processing ranges from salt washing to counter-current purification with hydroextraction of impurities.

This paper examines the nature of impurities in salt and explains the unit operations employed in the hydromechanical salt processes. It describes the salt testing methods relevant to prediction of the process performance, defines process efficiency and presents results obtained in industrial salt processing plants.

1. Salt production world-wide

Recently, the annual world production of salt has exceeded 250 million tons. Approximately one third of the total is produced by solar evaporation of sea water or inland brines. Another third is obtained by mining of rock salt deposits, both underground and on the surface. The balance is obtained as brines, mainly by solution mining. Brines can be used directly (for example in diaphragm electrolysis) or thermally evaporated to produce vacuum salt.

Salt type	World production
Solar salt	90’000’000 t/y
Rock salt	80’000’000 t/y
Brines	80’000’000 t/y
Total	250’000’000 t/y

The purity of washed solar salt produced in India and China reach 99 - 99.5% (NaCl, dry bases) but solar salt produced in Australia and Mexico is 99.7 – 99.8% pure. The purity of processed rock salt fluctuates between 97 and 99%+ in the USA and in Europe. Vacuum salt is usually 99.8 - 99.95% pure.

2. Salt consumption world-wide

The chemical industry is the largest salt consumer of salt using about 60% of the total production. This industry converts the salt mainly into chlorine, caustic soda and soda ash without which petroleum refining, petrochemistry, organic synthesis, glass production, etc. would be unthinkable.

Salt user	Salt consumption
Chemical industry	60%
Food	30%
Other	10%

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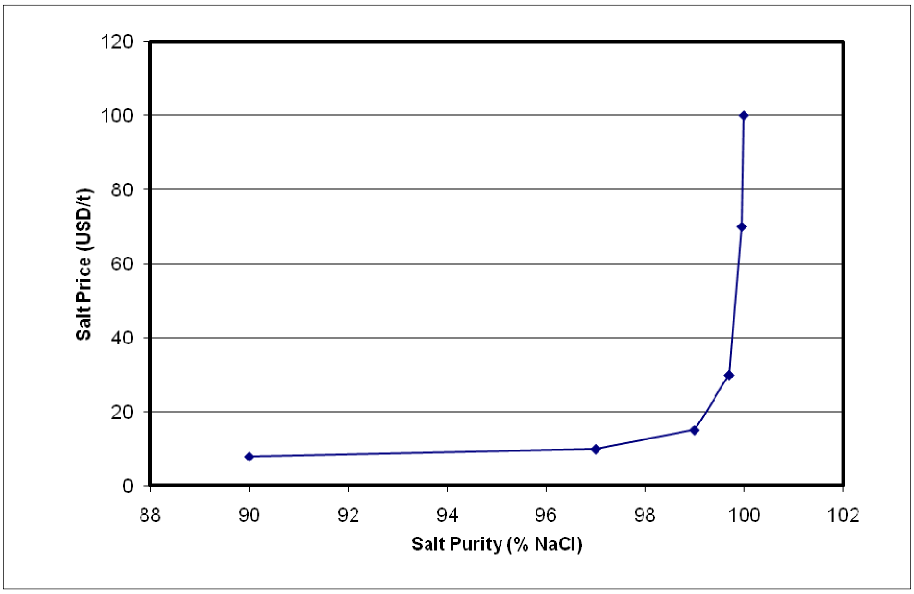
The second largest user of salt is mankind itself. Humans need about 30% of the total salt produced to support their physiological functions and eating habits. Salt for food is the most "taken for granted" commodity, available from thousands of sources in hundreds of qualities as table, cooking and salt for food production.



About 10% of salt is needed for road de-icing, water treatment, production of cooling brines and many other, smaller applications.

Whatever the use of salt, it is the sodium chloride in the salt that is required and not the impurities. The purer the salt, the more valuable it is (Ref. 12).

3. Impurities in natural salts

Sodium chloride in salt is always the same. It is the "non-salt" in salt - the impurities - that make the difference. In fact, the multiplicity of impurities in salt and their relative quantities are so variable that every salt needs to be considered on its own merits.

Except for insolubles, the origin of impurities is the sea water. Solar sea salts, as a rule just few months old, are rather similar. Rock salts, millions of years old, may vary greatly, from pure to dirty, from white to black. Lake salts contain components leached from the ground of the surrounding rocks in variable quantities. Salt lake chemistry is a science of its own.

Calcium sulphate is the most persistent companion of salt. In rock salt, calcium sulphate is found as anhydrite, hemihydrite or polyhalite. Gypsum is found both in sea salt and in lake salt. Natural brines are, as a rule, saturated with calcium sulphate.

	Rock salt	Sea salt	Lake salts	Brines
$CaSO_4$	0.5 - 2%	0.5 - 1%	0.5 - 2%	Saturated
$MgSO_4$	Traces	0.2 - 0.6%	Traces	Traces
$MgCl_2$		0.3 - 1%	Traces	
$CaCl_2$			Traces	
Na_2SO_4			Traces	
KCl			Traces	
NaBr			Traces	
Insolubles	1 - 10%	0.1 - 1%	1 - 10%	

Magnesium salts are always present in the sea salt, usually at a ratio of approx. one and a half weight units of magnesium chloride to one weight unit of magnesium sulphate. In lake salts, magnesium sulphate is usually accompanied by sodium sulphate, for example in

Sambhar Lake salts from Rajasthan in India or in Azraq salts from Jordan. Magnesium chloride also occurs together with calcium chloride, for example in the Dead Sea brines where also potassium chloride and sodium bromide are found in exceptionally high concentrations. Insolubles are present in salts of all origins in greatly fluctuating quantities.

3.1. How do impurities in salt effect the chemical industry?

In the chemical industry, salt is mostly dissolved together with the impurities in water or brine. Prior to feeding to the process, the brine is purified. Failure to purify the brine may have serious, even lethal consequences.

3.1.1. Hydrogen evolution

In electrolytic cells, excessive magnesium causes hydrogen evolution on the anode. Hydrogen and chlorine form an explosive mixture. Explosion in the cells or in the chlorine liquefaction may damage the equipment and release chlorine to the environment. Chlorine gas is highly poisonous. Stringent safety measures are taken in the chloralkali industry to avoid this to happen. The elimination of magnesium is of prime concern.

3.1.2. Mercury butter

Impure brine in mercury cells will cause butter formation. Butter will disturb mercury flow, causing short circuits that burn the electrodes. Alternatively, a large electrode gap must be maintained which will increase the power consumption. Butter removal will expose workers to mercury vapours that are damaging to health. Disposal of mercury butter is costly and undesirable for the environment.

3.1.3. Contaminated sludge

Sludge from brine purification in chloralkali plants with mercury cells is contaminated with mercury. Sludge decontamination by distillation requires high temperatures, is costly and never complete. The disposal of mercury contaminated sludge is environmentally objectionable and very costly. Avoiding the formation of sludge is better than having to dispose of it. This requires salt of high purity.

3.1.4. Membrane damage

Calcium and magnesium will damage the ion exchange membranes irreversibly. Erratic impurity content in salt may cause hardness breakthrough to the membrane cells. Membranes cost a fortune. Prices of USD 600 - 1’000 / m^2 have been reported. The purer the salt, the more remote is the danger of membrane damage.

3.1.5. Encrustation

In soda ash production, excessive sulphate reduces the value of the product. Accumulating calcium in the process causes encrustations. Periodical scale removal is costly and leads to loss of production.

Salt may be a cheap commodity. But impurities in salt and their removal cost in many cases more than the salt itself.

3.2. How does the chemical industry deal with impurities in brine?

In the chemical industry, impurities in brine such as calcium and magnesium are precipitated with chemicals. Sulphates are removed either by precipitation with barium or calcium or are controlled by purging the brine.

The main cost associated with brine purification is the cost of chemical reagents and the investment and operating cost of the brine treatment plant. In mercury cell plants, the cost of contaminated sludge disposal and purge decontamination is also substantial. In the membrane cell plants, the loss of salt in purge is much higher than in the mercury cell plants, reaching 30% with a salt feedstock containing some 0.7% of sulphate.

3.3. What do impurities in salt mean to the food industry?

Quality conscious consumers demand pure products. As one of the raw materials, salt must fulfil stringent specifications, otherwise the product quality may get adversely effected.

Crystal salt, whether stored in silos or used in a shaker, must retain its free flowing properties. Magnesium on the surface of the salt crystals absorbs humidity from the air and makes the salt damp. Silos cannot be emptied and shaker holes get blocked. The salt looses market and value.

4. Salt refining by vacuum crystallisation

The highest standards of quality are set by vacuum salt. Usually, vacuum salt is produced from brine obtained by cavity mining of underground deposits and chemically purified. Vacuum evaporating plants and their operation are costly and so is the vacuum salt. When it is crystallized from brine containing up to 4% of sulphate, vacuum salt contains sodium sulphate, frequently some 300 - 1’000 ppm or more. Despite the low calcium and magnesium content in the 1 - 10 ppm range, vacuum salt will seldom exceed 99.95% purity (Ref. 5).

5. The economical alternative: Salt processing

If impurities are removed from salt directly, without dissolution and recrystallisation, substantial cost savings can result. Simple washing will remove some of the impurities. But the more you wash, the more you lose. So the question is: How to get higher purity with less losses? And still do it with enhanced overall economy?

The most obvious and simple way of removing soluble impurities from salt is spraying of brine or water over a layer of salt - on a heap, on a screen, on a wire mesh belt or in a screw conveyor. The disadvantage is that the brine will flow downwards through a path of least resistance, forming channels. Washing takes place within the channels but not

between them. Downwards flowing brine cannot displace the air between the crystals. Where there is air, there is no brine and thus no washing. That is why the spraying methods have a limited efficiency. The picture above shows a plant that dissolves more salt than it is designed to produce.

Salt must be completely submerged in brine to remove the magnesium containing bitterns. Sufficient time is needed for the magnesium to leave the crevices in the crystals by diffusion. Obviously, very pure brine is needed to get the best purification. But pure brine is obtained by dissolution of salt in water and this leads to losses. The losses can be reduced with brine recycling, but then the purity is not achieved. This is the well-known dilemma of co-current salt washing.

Equipment that is frequently used to submerge the salt fully and then lift it from the brine is an inclined screw conveyor (classifier). The adjacent picture shows a classifier followed by a wire mesh drip-off conveyor belt.

High turbulence in the classifier causes carry-over of salt particles with the washing brine to the overflow that is directed to the adjacent settling pond. The salt particles are causing the milky appearance of the brine.

Another disadvantage of inclined screw conveyor is the fact that the rotating screw pushes the salt in the direction of the rotation. If the screw rotates anti-clockwise, then, viewed from the same direction, the salt is pushed to the right hand side of the trough. Brine leaving the salt will then flow preferentially against the salt, but on the side where the salt level is lower, that is on the left hand side. Thus, the brine does not


flow counter-currently through the salt, but it bypasses the salt. Therefore, the washing effect is limited. The pictures above show the left hand and the right hand side of the same inclined screw conveyor and the difference in level of the salt.

Salt Partners devoted much time and effort to the subject of salt processing. As a result, they invented a process that removes more impurities from salt, uses less water and recovers the dissolved salt to reduce the losses. The process also remove impurities that are inside the salt crystals - by selectively cracking the crystals to free the enclosed impurities, without formation of fines that increase the losses. The process achieves and exceeds the purity of 99.95% NaCl. Salt Partners gave their unique process a name: The **HYDROSAL** salt upgrading process with **HYDRO**EXTRACTION of impurities from **SAL**T.

5.1. How can chemical plants take advantage of salt upgrading?

A plant that obtains salt from a single source can upgrade the salt in the saltworks where it is produced - it is easier to dispose of the separated impurities there. When the salt comes from many places, then the salt upgrading can be integrated in the salt consuming plant. Depending on the type of salt, either the HYDROSAL-XP or the HYDROSAL-XC process can be selected. The HYDROSAL-XC process is usually more economical for upgrading of low quality solar salt, for dry salt deposits or for lake salts.

Salt upgrading helps to solve the problems associated with contaminated sludge and purge disposal. The overall salt consumption, the total investment and the operating cost are reduced. With pure salt of constant composition the brine plant operation becomes easier. In medium and larger plants, the investment in a salt upgrading plant is financed from the savings in brine purification chemicals typically within a couple of years.

5.2. Why can solar saltworks increase productivity with the HYDROSAL process?

In solar saltworks, salt is harvested from crystallizing ponds as a mixture of salt crystals and mother liquor containing soluble impurities in high concentrations. During storage, the content of soluble impurities is reduced, until is becomes constant after some 6 months. During this period, the humidity of the salt on the stockpile is about 3% but it drops down to approx. 1% thereafter. This phenomenon is known as "rain washing" or as "natural purification". Natural purification is the more accurate description because the purification occurs also when there is no rain.

Bulk density of the salt is about 1.2 t/m^3, specific gravity of salt crystals about 2.15 t/m^3. Thus the stockpile consists by half of salt and by half of air. Magnesium chloride on the surface of the crystals absorbs moisture from the air. The moisture dissolves sodium chloride. Salt cannot hold more than 3% of moisture. The absorbed moisture with the diluted impurities and with the dissolved sodium chloride slowly flows out of the stockpile and dissipates to the ground. The sodium chloride losses caused by this phenomenon are 10 - 12%.

Efficiency of conventional salt washing processes is typically 60% and salt losses reach 10%. When conventionally washed salt is stockpiled, the "natural purification" continues, leading to an additional loss of some 5% of NaCl. Thus, the overall salt losses are as high as 15%.

In addition, due to variations in the temperature and humidity, salt on the stockpile undergoes micro-recrystallisation of the crystal surface. Impurities on the crystal surface become covered with solid sodium chloride and the crevices in the crystals, full of impure mother liquor, are closed. Much of the impurities, originally accessible to purification, will become imbedded inside the crystals. This phenomenon is well known: "Old salt is more difficult to wash than fresh one".

The HYDROSAL-XP process purifies the freshly harvested salt completely. The "natural purification" effect and the related salt losses are eliminated. Since the sodium chloride losses in the HYDROSAL-XP process are only 2 - 3%, the effective salt production of the saltworks is increased. Salt of higher purity and value is available on the stockpile from the time of the harvest which matters when the salt is supplied to the chloralkali industry or for exports.

5.3. How can salt refineries benefit from the HYDROSAL process?

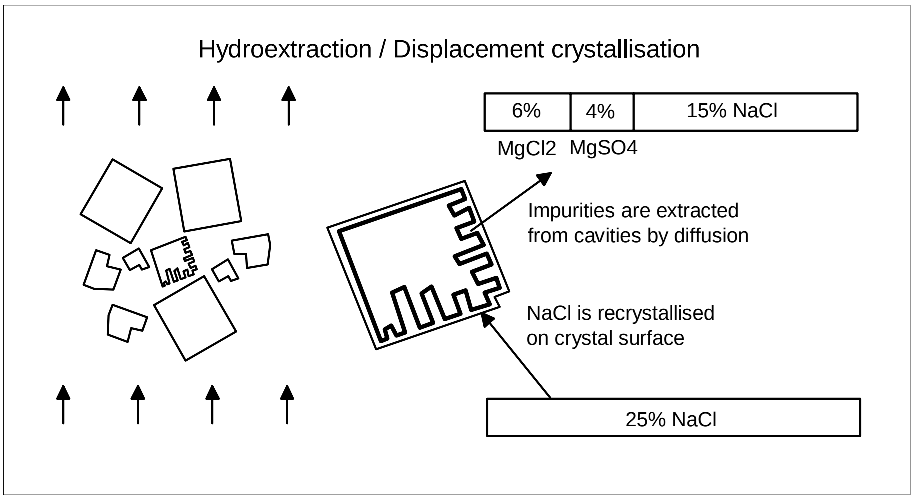
Solar salt is frequently used as a feedstock in salt refining plants. Traditional salt processing in mechanical refineries consists of washing, drying, crushing and screening. Salt washing removes surface impurities and drying removes surface moisture. But salt crystals contain impurities enclosed inside. When salt is crushed after drying, the impurities are set free. The solid impurities spoil the whiteness of the salt. Magnesium containing mother liquor spills out of fractured cavities, freeing its hygroscopic power. The salt begins to absorb moisture from the air and becomes damp and sticky.

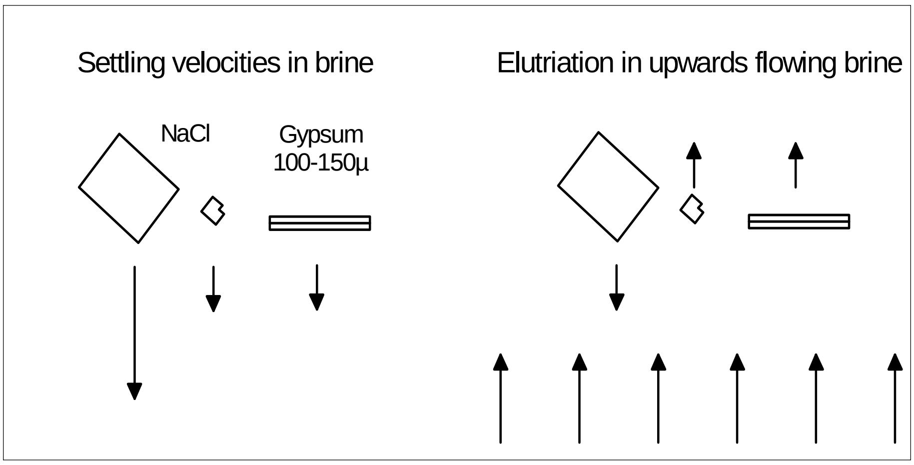
In the HYDROSAL-XM process, hydromilling selectively ruptures the salt crystals where the impurities are embedded so that they become exposed to purification. Purities of 99.97% have been reached with natural solar salt. Hydromilling provides the crystals with rounded form resulting in superior free flowing properties of the product. Hydromilling also remarkably improves the whiteness of the salt.

HYDROSAL-XM process followed by drying, screening, additive blending and packaging is known as the HYDROSAL-XRT (**R**efined **T**able salt) process. In the market, HYDROSAL-RT refined salt can match the quality of vacuum salt at substantially lower production cost.

5.4. What unit operations to employ for removal of soluble impurities?

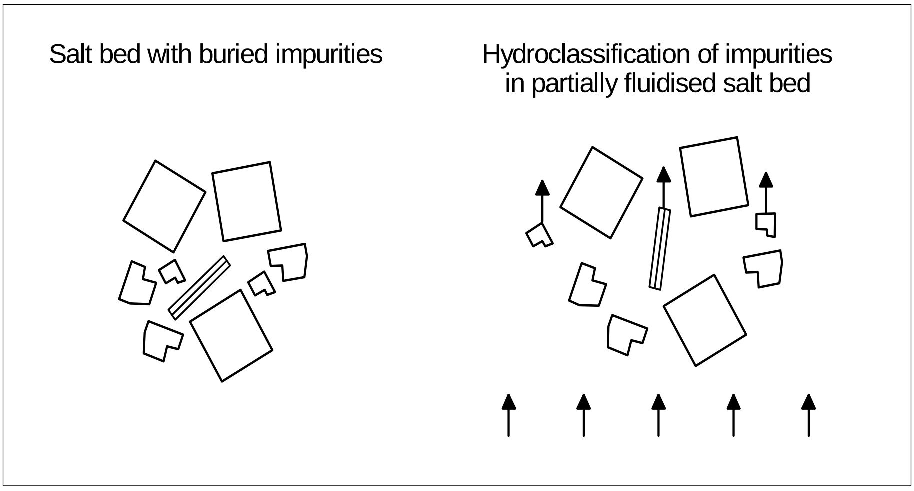
Here is how the HYDROSAL process solves the problem of maximising the salt purification by employing very pure brine and minimising the salt losses at the same time: It takes the least valuable salt fraction, the fines, and dissolves them in a small amount of water, forming pure saturated brine. Then it allows the brine to flow - slowly and upwards, counter-currently - through a layer of downwards moving salt crystals. Each salt crystal is completely encompassed by the pure brine so that every soluble solid impurity has the opportunity and time to dissolve. Also the impurities entrapped in the crevices have enough time to leave.





As the brine is progressing upwards, it picks up more and more magnesium and its density goes up. Just as the density of brine in the saltworks increases with the progress of crystallization, the salt crystallizes from the upwards flowing brine on the surface of the downward moving crystals. This benefits the product purity because the crystal surface of the processed salt consists of pure, recrystallised sodium chloride. The salt losses in the process are reduced because the dissolved salt fines are thus recovered. It is called hydroextraction with displacement crystallization. It is simple and it makes sense.

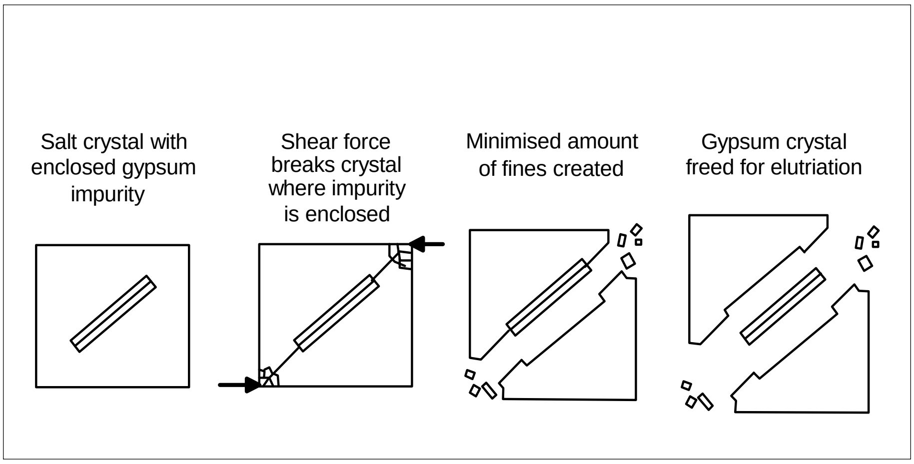
5.5. How to remove insoluble impurities?



Fortunately, most of the insolubles consist of fine dust from the air or clay from the bottom of the crystallization ponds. Also gypsum crystals are fine needles, just a fraction of a millimetre long. Brine sprayed over a salt layer is supposed to wash the fine insolubles down but the salt layer acts as a filter, holding the fines back, particularly when the salt is rather fine. That is why the content of calcium and insoluble matter in the salt washed on a heap is almost the same before and after the washing.

In the HYDROSAL process, brine is forced to flow upwards against the downwards moving salt crystals, pushing them apart (fluidizing them) so that the fine particles are free to float upwards out of the salt and to the overflow of the process vessels. The brine velocity is precisely controlled to remove just the right size of particles containing as much impurities as possible but very little salt. This is called elutriation and hydroclassification.

5.6. How to remove impurities from the inside of the salt crystals?



It is obvious that we have to break the crystals. But how? If the crystals are crushed with a hammer, they break in thousands of pieces. The fines formation is high and the salt losses are heavy.

But if we apply shear force to the crystal, it will break gently along the planes where it is weakest. It is weak where the impurities disturb the crystal structure. In this way we access the inclusions selectively without an excessive loss of salt. This is called selective rupturing. Depending on the application, the salt is ruptured dry in the HYDROSAL-XC process or as a mixture of salt and brine in the hydromill of a HYDROSAL-XM plant.

5.7. How are the unit operations in the HYDROSAL process organised?

Let us begin at the end. The last step of any salt purification process is the separation of the purified salt from the brine. This happens best in a centrifuge. The centrifuge of a vibrating resonance type gives salt with an economical minimum of moisture and recovers the maximum of the valuable pure brine. Centrifuges produce salt fines by mechanical abrasion. In the HYDROSAL process the fines are utilized for production of pure brine in a dissolving vessel. From there the pure brine is returned to the vessel from which the salt and brine flow to the centrifuge. This vessel is called the hydroextractor. The lower part of the hydroextractor is called the hydroextraction zone. Above the hydroextraction zone, the hydroclassification zone is located.

From the overflow of the hydroextractor the brine flows to the elutriator where it is mixed with the incoming salt. In the elutriator, the brine flows upwards against the freely falling salt and carries the fine insoluble impurities to the overflow. Overflowing brine is directed to a settling pond where the insolubles are collected. Clarified brine is returned to the process. Water added to the process leaves the process carrying soluble impurities away. This sequence of unit operations is called the HYDROSAL-XP (E**XP**erience) and is common to all the HYDROSAL process variants.

In the HYDROSAL-XC process (with **C**rushing) the salt is selectively ruptured in a special type of shear force dry rupturing equipment operating with a precisely defined gap and a predetermined differential velocity. The energy and raw salt consumption are somewhat higher in the HYDROSAL-XC process but the process can achieve higher upgraded salt purity, particularly when the salt upgradability curve is steep.

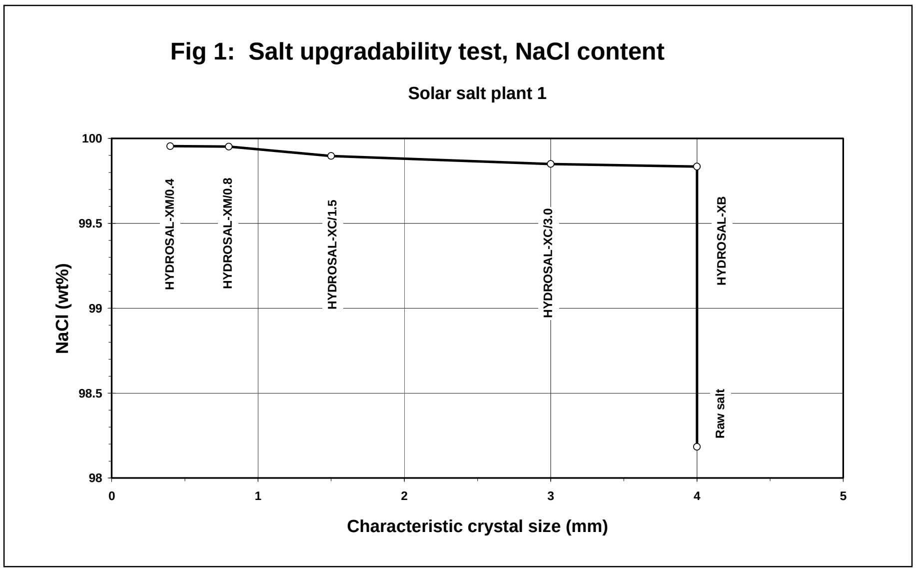
The HYDROSAL-XM process (with hydro**M**illing) is employed where top salt quality is required and where the higher investment cost, energy and raw salt consumptions are justified. The salt is first treated in a sequence corresponding to the HYDROSAL-XP or HYDROSAL-XC process, then passed through the hydromill and purified again in a process similar to the HYDROSAL-XP sequence. Since the salt product is very fine, pusher type of centrifuge must be used. The HYDROSAL-XM salt can be used in the chloralkali industry, but usually it is dried, screened, conditioned with additives and packed to ensure the best appearance, cleanliness, brilliant whiteness and excellent free flowing properties appreciated in the food market.

5.8. How to predict the salt purity achievable with the HYDROSAL process?

Even the best understanding of the principles of impurity removal cannot be transformed into a quantitative prediction of the achievable purity. This is only possible by testing the salt in the laboratory, using a sequence of unit operations that is identical to the sequence employed in the relevant process. Salt Partners have developed and standardized such procedure and used it to investigate hundreds of salt samples.

1. First, the raw salt is analysed. The raw salt analysis represents the sum of two unknown values: the surface impurities that are removable and those that are not. It is obvious that the raw salt analysis alone cannot give the information how much impurity can be removed and to what degree of purity the salt can be treated.

2. The next step is to find out, how much impurity can be removed without any change of the salt granulometry. This is called the HYDROSAL-XP upgradability test.



3. Then we find out how much of the impurities enclosed inside the crystals can be removed if the salt is subjected to dry selective rupturing. Two characteristic crystal sizes, 1.5 and 3 mm, have been established as a standard (HYDROSAL-XC/1.5 and HYDROSAL-XC/3 upgradability test).

4. This is followed by a test with hydromilling (HYDROSAL-XM test). Here, 0.4 and 0.8 mm characteristic crystal sizes are used as a standard (HYDROSAL-XM/0.4 and HYDROSAL-XM/0.8 refinability test).

5. If table salt production is intended, the HYDROSAL-XM salt is specially treated to produce salt that is blended with additives and analysed with respect to whiteness and free flowing characteristics. This is then called the HYDROSAL-XRT refined table salt test.

The analytical results are plotted against the characteristic crystal size. The resulting graphs are called the upgradability curves. The curves are produced separately for calcium, magnesium, sulphate and insolubles. The analysed impurities are stoichiometrically combined to calculate the sodium chloride content. Potassium chloride and sodium bromide are usually not considered as impurities. The results are summarized in a report. Samples from all tests are sent to the client and a second set is kept by Salt Partners for records.

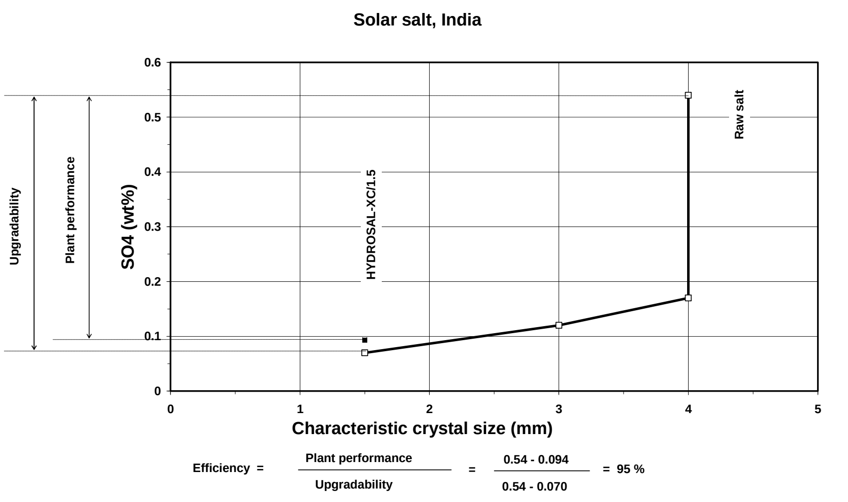
The test procedures and the analytical methods are given to clients who are encouraged to use them for control of their salt quality and the performance of their HYDROSAL plants. Thus, Salt Partners and their clients are able to refer to salt qualities and upgradabilities determined using consistent methodology over the years for the purpose of records, development or determination of plant performance guarantees.

5.9. How is the efficiency of a HYDROSAL plant defined?

Industrial plants may show different efficiencies than the laboratory procedures that simulate them. In the HYDROSAL process, turbulence and back-mixing reduce the purity of the product compared with the laboratory test. It is therefore important to define precisely the plant efficiency and to monitor the plant performance accordingly.

In the practise of the HYDROSAL technology, the ratio between impurities removed in the plant and those removed in the corresponding upgradability test carried out with the same raw salt is defined as the plant efficiency.

Fig 2: Plant efficiency calculation for sulphate

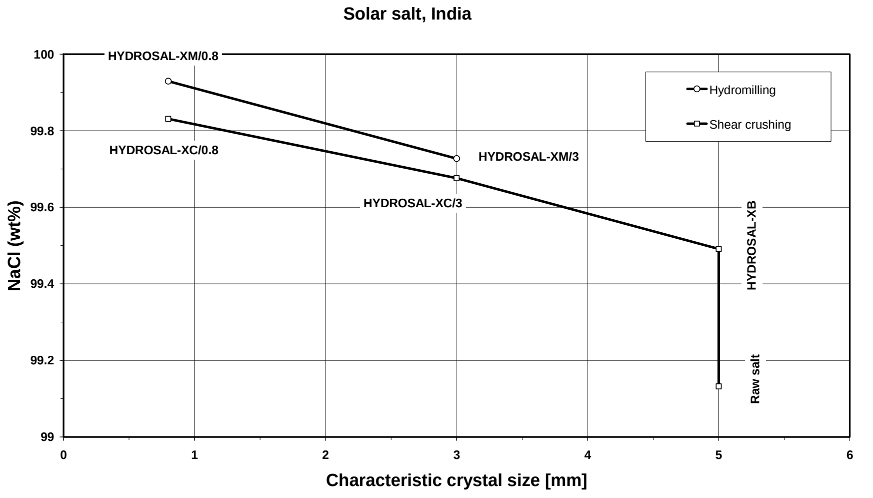


5.10. How to determine the most economical HYDROSAL process option?

The finer the salt is ruptured or hydromilled, the purer it can be made. The purer the salt should be, the higher is the energy and raw salt consumption and the more expensive is the HYDROSAL plant. Obviously, an optimum exists where the benefit is maximised with the minimum of cost.

For example, if the upgradability curve is flat and the upgradability of the salt is good, the additional expense of the HYDROSAL-XC or HYDROSAL-XM process doesn't pay and the HYDROSAL-XP process only is justified (Compare the upgradability curve, Fig 1). If the upgradability curve is steep, the HYDROSAL-XC process becomes justifiable. If strict purity limits exist that must be attained, the HYDROSAL-XM process may have to be selected (Compare the upgradability curve, Fig 3).

Fig 3: Salt upgradability test: NaCl content



The method of finding out the economy of the HYDROSAL process and selection of the most economical processing option for industrial application is simple: Savings are calculated as the difference in cost of brine purification chemicals with the existing salt and with the HYDROSAL upgraded salt. The savings are compared with the investment cost and the minimum payback is determined. The process with the shortest payback is then recommended as the most economical option.

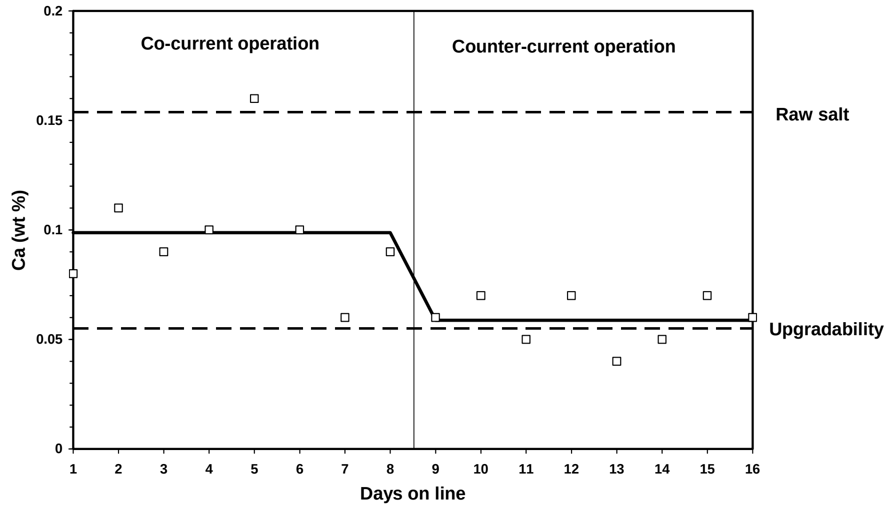
If required by the client, more complex feasibility studies are elaborated, involving various salt sources, complicated logistics, combined production of upgraded salt for chloralkali processes and refined salt for human consumption, expansion or conversion into membrane technology, export intentions, etc.

5.11. How does the HYDROSAL process perform compared with conventional processes?

In one of the first salt upgrading plants incorporated in a membrane cell chloralkali plant, we had the opportunity to compare the process efficiency with the same salt, once with co-current and then with counter-current flow of brine.

Fig 4: Co-current vs. counter-current process performance

Solar salt, plant 2



With co-current flow of brine, the hydroextraction and hydroclassification stages were out of operation. When the counter-current flow was established, the hydroextraction and hydroclassification became operative and the performance of the plant has markedly improved. The results illustrate the effectiveness of hydroextraction and hydroclassification that are inherent to the HYDROSAL process.

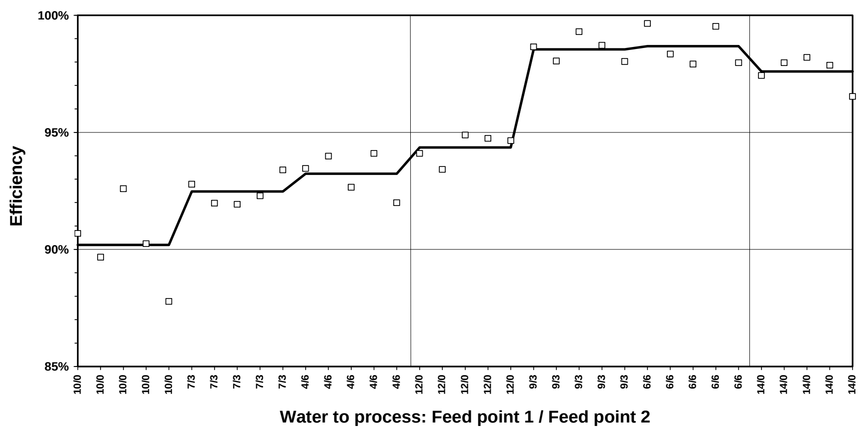
	Upgraded salt with co-current flow	Efficiency with co-current flow	Upgraded salt with counter-current flow	Efficiency with counter-current flow
Ca	0.092%	69%	0.06%	96%
SO_4	0.31%	65%	0.21%	92%

5.12. How efficient is the HYDROSAL process in the industrial practise?

One of the largest hydroextraction plants, a 130 t/h solar salt upgrading plant in Spain, has undergone a rigorous commissioning test. During the test, the water input and the distribution of water in various injection points were optimised. Whereas at the beginning of the test the plant efficiency was fluctuating around 90%, it reached 98 - 99.5% when the optimum

Fig 5: HYDROSAL optimisation test, NaCl efficiencies

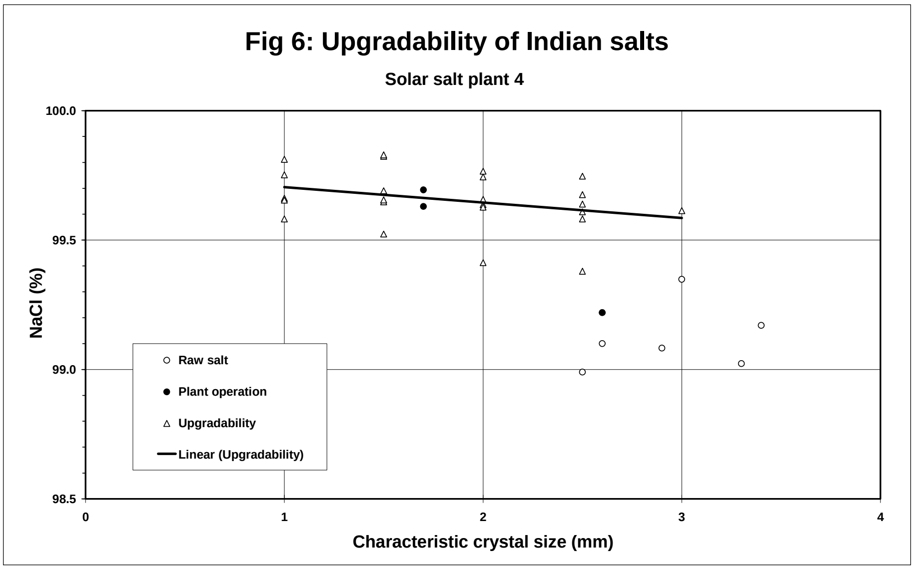
Solar salt, plant 3



operating parameters were found. The plant operates only during the salt harvesting season. Still, the investment in the plant has been paid back in 2 ½ years with the savings on brine purification chemicals and with the reduction of salt losses compared to the previously employed conventional salt washing plant.

5.13. How does the HYDROSAL process perform with salt of variable quality?

Several salt upgrading plants with hydroextraction were built in India, many of them integrated in chloralkali plants. These plants buy salt in Gujarat in the north and in Tamil Nadu along the southern and eastern coast of India. The salt is washed in the saltworks by spraying water on the heaps. After the washing the salt is 99.0 - 99.4% pure. The upgradability of these salts varies widely. There are some excellent salts available but some rather poor salts that can be hardly upgraded or refined. The best upgradable salts are purified in the salt upgrading plants with hydroextraction of impurities to up to about 99.7% purity.



5.14. How does HYDROSAL refined table salt compare with vacuum salt?

Refined salt for human consumption should be pure and white. The purity of HYDROSAL refined salt matches, or even exceeds, the purity of vacuum salt, although there are differences. Whereas the impurities in the HYDROSAL salt consist of $CaSO_4$, $MgSO_4$ and $MgCl_2$ in the natural proportions, the main impurity in the vacuum salt is Na_2SO_4, the residuum of the chemical brine purification.

		HYDROSAL-XRT/0.4 Salt plant 1	Vacuum salt from Switzerland
$CaSO_4$	ppm	136	17
$MgSO_4$	ppm	55	5
$MgCl_2$	ppm	74	
Na_2SO_4	ppm		420
Insolubles	ppm	20	20
NaCl	%	99.972%	99.954%

The whiteness of HYDROSAL refined salt often exceeds the whiteness of vacuum salt substantially. The special hydromill employed by Salt Partners in the HYDROSAL-XM process has the unique capability of removing yellow colour from salt and giving it a slight bluish / greenish tinge that makes the salt appear even whiter.

	E	L	a	b
Vacuum salt from Switzerland	5.15	-5.08	-0.72	-0.5
HYDROSAL-XRT/0.4, Salt plant 1	2.79	-2.58	-0.75	-0.74

Explanation:

- E is $\sqrt{L^2+a^2+b^2}$ and expresses the overall deviation from ideal white.
- L is the darkness. 0 is ideal white and -100 is ideal black.
- a is the green / red axes. -60 is ideal green, +60 is ideal red.
- b is the blue / yellow axes. -60 is ideal blue, +60 is ideal yellow.

6. How to improve solar salt upgradability?

Upgradability of salt is closely correlated with the content of impurities inside the salt crystals. For example, the HYDROSAL-XP upgradability of the salt shown in Fig. 1 is 99.83%, the HYDROSAL-XP upgradability of the salt shown in Fig. 3 is only 99.49%. This means that the content of impurities inside the salt crystals shown in Fig. 1 is 0.17%, inside the salt crystals shown in Fig. 3 it is 0.51%, or three times more. This also means that the salt shown in Fig. 1 can be upgraded in the less expensive HYDROSAL-XP plant to world class purity, whereas the salt shown in Fig. 3 has to be crushed and treated in a HYDROSAL-XC process or hydromilled and treated in a two stage HYDROSAL-XM process to reach the same purity. It is evident that production of well upgradable solar salt is highly desirable.

But how come that some solar salts have more and other salts have less impurities inside the crystals? That some salts are better upgradable that other salts? This depends mainly on the quality of the brine (mother liquor, bitterns) and on the way how the salt is crystallised. For example, if the brine is oversaturated with respect to calcium sulphate before it enters the crystallising ponds, the salt will contain high percentage of gypsum. If the brine is left in the ponds too long, the salt will contain high percentage of magnesium. These are just two simple examples of important operating parameters that influence salt upgradability, but there are many more. Salt Partners offer technology related to the physical and chemical aspects of solar salt production and upgradability improvement under the trade name SOLARSAL.

Solar saltworks are not just water pools with some chemistry in it, they are also complex biological systems with many living species (Ref. 3). If the biological system is well balanced and all nutrients entering and generated in the saltworks are consumed, then biologically purified, concentrated brine will feed the crystallisers and large, hard, transparent, odourless and well upgradable salt crystals will grow (Ref. 4). Salt Partners market systems for biotechnological solar saltworks management under the Registered Trademark BIOSAL.

7. Key Words

Solar salt, salt processing, chloralkali, HYDROSAL

8. Salt Partners

Salt Partners Ltd., Zurich, Switzerland, is an internationally renowned, independent firm of salt consultants and engineering contractors, active in the field of salt production, processing and hypersaline biotechnology. Salt Partners' reputation is based on more than 30 years of experience gained in salt projects implemented all over the world.

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