

Four Years of Brine Production by Solution Mining: The Pimai Project in Thailand

Paul Grönefeld¹, Yukyo Yoshida², Mahabir Koder³ and Tawan Bunpapong³

¹*Kavernen Bau- und Betriebs-GmbH, Germany*

²*Nihon Dry Chemicals Co. Ltd., Japan*

³*THASCO Chemical Co. Ltd., Thailand*

ABSTRACT

Following comprehensive planning and construction, the leaching process for a salt production project by THASCO Chemical Co. Ltd. in Pimai, Thailand, was started in September 1987. Some four years of operational experience of brine production by solution mining have now accumulated. The planning projections and the actual operating data are compared.

Planning predictions of the leaching process were tested. The number of production wells required to meet project targets, as originally calculated with the aid of the computer simulation program, was confirmed. Predictions of brine concentrations and the evolution of cavern shape, made with the help of leaching process simulation software, were checked by means of salinity measurements and sonar surveys. Experience and knowledge gained in brine level monitoring, using control pipes during brine production, is now available. In addition, information on the operational behaviour of the facility was collected.

INTRODUCTION

Brine production began in September 1987 from the dissolution of salt from the lower layer of the Maha Sarakam Formation in Pimai, Thailand (Salakshana et al., 1987).

A detailed planning phase had preceded the production of brine. In addition to geological investigations, rock mechanical core tests and stability calculations (Institute for Underground Construction, 1985), as well as the design of the surface and underground plant, a leaching concept (Kavernen Bau- und Betriebs-GmbH, 1985) was worked out with the help of a leaching simulation program to fulfil the project demands. After four years in operation it is now possible to compare the planning predictions with the actual operational data covering the following aspects: number of production wells, leaching process hydraulics, concentration evolution, volume evolution, as well as monitoring (blanket level control).

This paper describes the solution mining process in particular, its planning, implementation and monitoring as well as the experience gained from four years of operation.

BRINE PRODUCTION BY SOLUTION MINING

The production of brine from the lower salt layer of the Maha Sarakam Formation is achieved by the circulation of fresh water via bore holes. The principle behind the solution mining technique is shown in Fig. 1.

Two freely suspended tubing strings are run into the well, which has been cased and cemented down to the top of the salt bed. This gives three separate surface-to-cavern pipe or annulus connections. Water is pumped through one of the tubing strings into the well. The water dissolves the salt at the exposed well surface, becoming variably saturated. Brine returns to the surface via the second tubing string. A gas or liquid medium — lighter than the brine but which does not dissolve salt — is injected into the well via the third connection. This medium, known as the blanket, is designed to prevent dissolution of the salt in an upward direction. The control of this brine production process (concentration and volume evolution) is achieved with the time dependent leaching parameters such as leaching string depth, blanket depth, pumping rate etc., as laid down in the leaching plan.

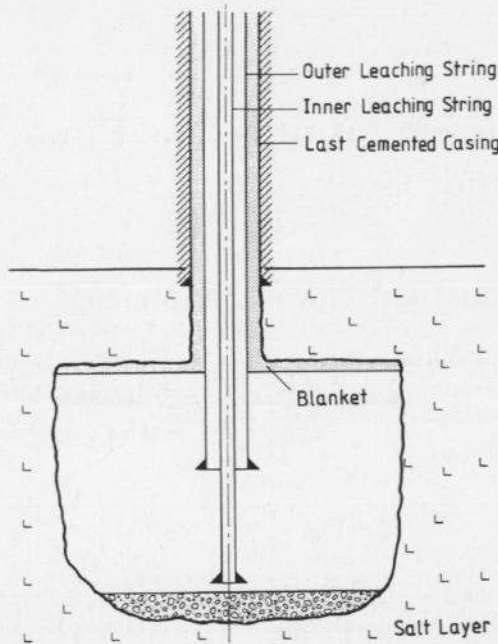


Fig. 1. Solution mining process with blanket.

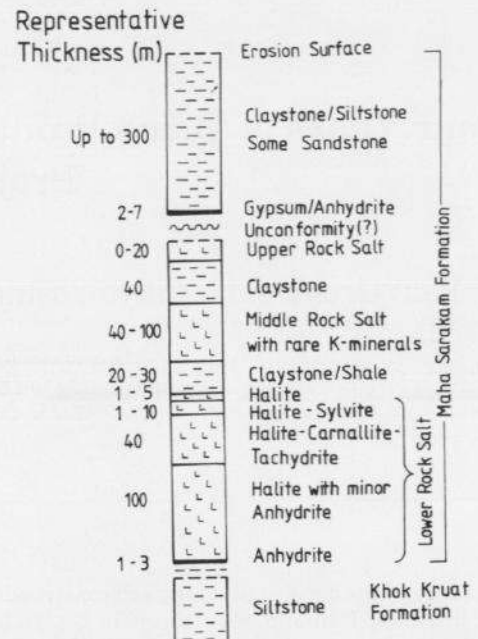


Fig. 2. Stratigraphic column of Maha Sarakam formation.

PROJECT BACKGROUND AND AIMS

Many factors must be taken into consideration when planning the solution mining technique and developing the leaching concept, including:

- the known geological conditions (Fig. 2)
- the physico-chemical properties of the salt as determined by core analysis
- the limits of stability as determined by rock mechanical calculations (Fig. 3).

It was also hoped to achieve the following goals in the Pimai project:

- production of around 350 t/d of saturated NaCl brine (> 300 kg/m³) after 3 months
- maximum extraction of salt from a borehole — within the rock mechanical limits
- use of a minimum number of wells to achieve the production targets

This paper discusses the hydraulic aspects of the plant design. Moreover, the design, implementation, and monitoring of the solution mining technique will also be described in detail.

LEACHING PROCESS HYDRAULICS

The hydraulics of the leaching process are mainly determined by the following factors:

- maximum pumping rate required to achieve the desired daily salt production targets
- maximum permissible pressure on the shoe of the last cemented casing string to prevent rock fracturing

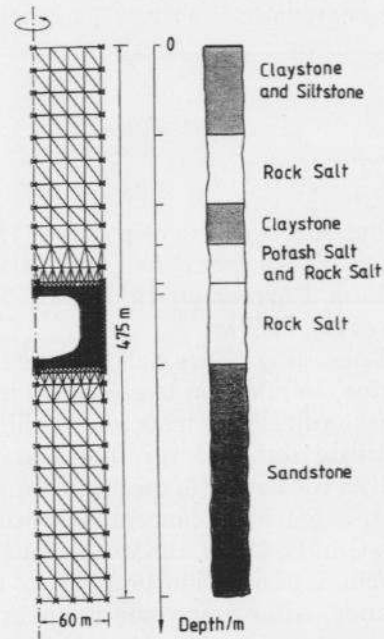


Fig. 3. Characteristic simulation model and discretization in finite elements.

- lengths of the surface pipe system
- process procedures (e.g. connecting two wells in series to enhance brine saturation)

Hydraulic calculations are necessary for the design of:

- pumps

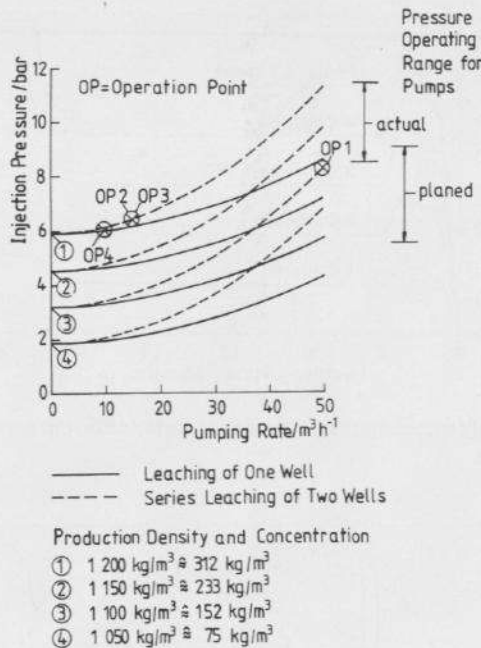


Fig. 4. Injection pressure vs. pumping rate.

- borehole dimensions (size of the last cemented casing)
- leaching string combinations
- dimensions of the pipe system

Figure 4 shows the expected pump pressures dependent on the pumping rate, the production concentration and the operation mode. In addition, four operation points were determined for realistic operation modes to help in the selection of the required pump pressure range.

However, the actual operation of the leaching process revealed — because of higher than expected friction losses from deposits in the pipes and the leaching strings — that the planned pump pressure was insufficient (Fig. 4). Happily, the modifications to the pumps could be carried out without significant changes to the overall scheme.

DEVELOPMENT OF THE LEACHING CONCEPT

A computer program capable of simulating the leaching process was used to develop a production method which could achieve the project goals. The input data for the computer program consisted of data specific to the rocksalt layer (time independent) i.e.:

- dissolution rate
- chemical composition
- insoluble content
- bulk density

and also data specific to the solution mining process (time dependent) i.e.:

- density of insolubles
- salt density
- leaching string setting depths
- blanket depths
- pumping rates
- leaching process, direct/indirect
- salt concentration of injected liquid (leaching caverns in series)

The numerical calculation of the leaching process takes place at certain time intervals. Leaching simulation results are given for the following:

- time intervals between changes
- daily cavern size increase
- gross and net cavern volume
- volume of insolubles sedimented on the cavern floor
- concentration of produced brine
- daily and cumulative mass of salt produced
- cavern shape

In this way a basic leaching concept was put together.

RESULTS OF THE LEACHING PROCESS MODELLING

The produced brine concentration is basically dependent upon the available surface area of the salt that can be leached, and the length of time that the injected water is in contact with this salt surface (e.g. a low pumping rate and a large cavern volume result in a long contact time).

At the very beginning of the leaching process, the only dissolution surface available is that of the original borehole wall — the brine concentration will therefore be low even at reduced pumping rates.

To achieve the project goals it was therefore necessary to create as large a cavern as possible, within the first three months. It was therefore essential from the start to pump at the technically allowable maximum rate — 50 m³/h.

In order to realise the economic demands — but always taking into account the rock mechanical limitations — for maximum salt extraction with high brine concentrations it was necessary to formulate a stepwise development strategy.

This required that the blanket level be raised step by step at prescribed volume intervals. Figure 5 shows a schematic representation of cavern shape evolution along the lines of the previously described method.

The optimisation of the leaching concept with the help of the computer simulation program, and based

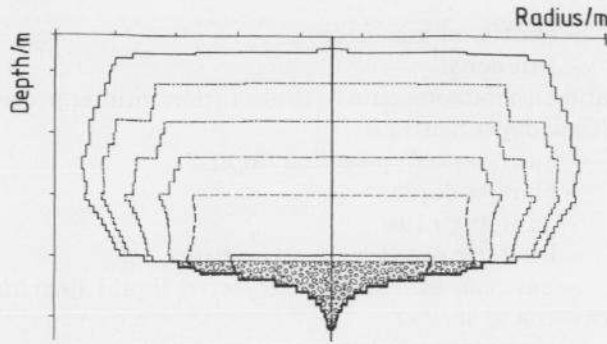


Fig. 5. Cavern shape development.

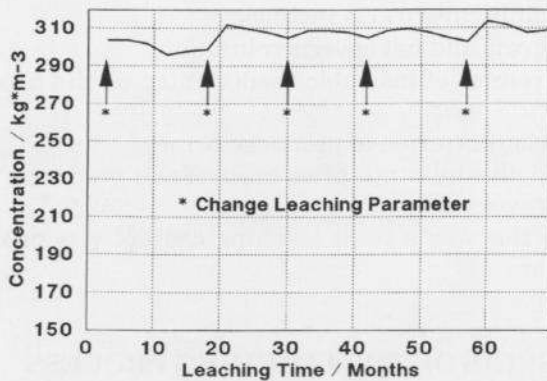


Fig. 6. Brine concentration vs. leaching time.

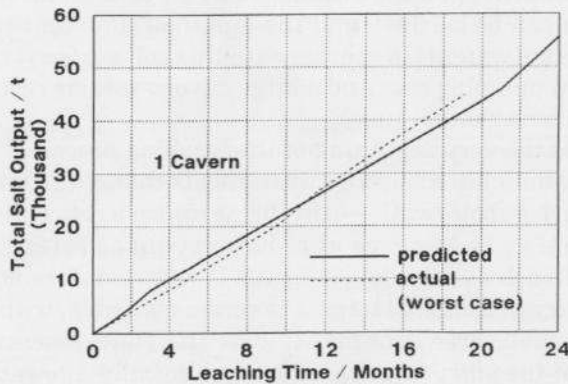


Fig. 7. Total salt output for one cavern vs. leaching time.

on the above mentioned basic procedure, gave the expected brine concentration development as shown in Fig. 6, and a salt extraction from one borehole as shown in Fig. 7, as well as a volume evolution (Fig. 5).

The projection of the salt extraction per borehole onto the planned production profile after the ninetieth leaching day, revealed that five production boreholes would be required (Fig. 8).

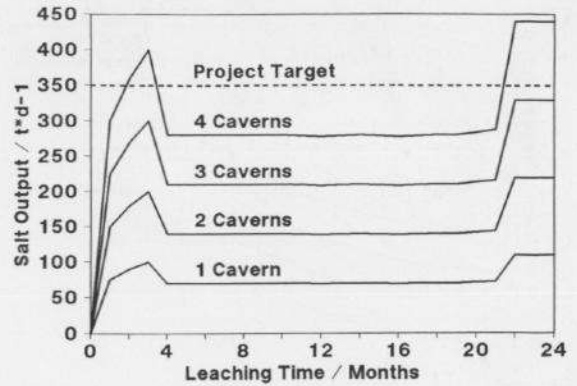


Fig. 8. Daily salt output vs. leaching time for different numbers of caverns.

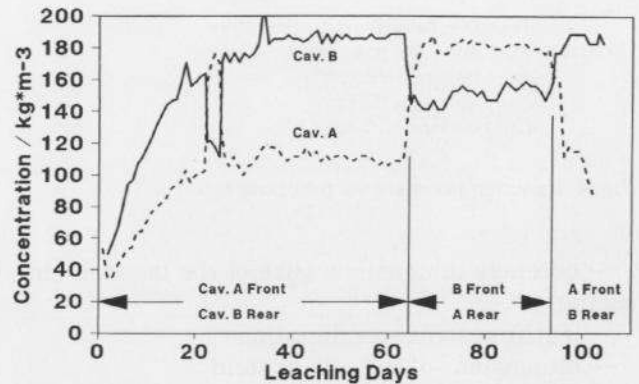


Fig. 9. Actual produced brine concentration vs. leaching days for Caverns A and B.

IMPLEMENTATION AND MONITORING OF THE LEACHING PROCESS

In September 1987, on the basis of the leaching concept described above, brine extraction began from two production boreholes. As previously mentioned, at the beginning of the leaching process the concentration of the produced brine is very low — especially at high pumping rates; however it was possible, because of the flexible design of the plant, to pump the under-saturated brine from the first borehole into the second borehole to thus increase the saturation.

Tables 1 and 2 show the daily leaching parameters of cavern A and B from the first days (approx. three months) of actual operation:

- injection rate
- cavern combination
- injected water concentrations

The actual brine concentrations produced can be seen in Fig. 9.

The available data on the actual operation were used to history-match the computer simulation and

TABLE 1

Leaching parameters for Cavern A

Leaching Days d	Leach. Rate m ³ /h	Cavern Comb.	Injected Conc. kg/m ³
1. - 62.	47,7	A → B	8,0
63. - 71.	42,5	B → A	140,0
72. - 81.	44,8	↓	152,0
82. - 91.	44,6	↓	155,0
92. - 93.	50,0	A → B	12,0
94. - 95.	49,9	↓	33,0
96. - 97.	48,5	↓	30,0
98. - 99.	49,2	↓	21,0
100.	33,3	↓	14,0

TABLE 2

Leaching parameters for Cavern B

Leaching Days d	Leach. Rate m ³ /h	Cavern Comb.	Injected Conc. kg/m ³
1. - 5.	41,0	A → B	42,0
6. - 9.	48,9	↓	60,0
10. - 13.	46,8	↓	78,0
14. - 21.	46,3	↓	95,0
22. - 29.	46,2	↓	107,0
30. - 62.	45,3	↓	112,0
63. - 91.	42,1	B → A	18,0
92. - 93.	51,7	A → B	160,0
94. - 95.	50,0	↓	115,0
96. - 97.	48,6	↓	115,0
98. - 99.	49,3	↓	105,0
100.-103.	51,1	B	17,0

thus bring it into line with the actual conditions experienced.

A comparison between the actual development in brine concentration and the history-matched computer projection is shown in Figs. 10 and 11. On the strength of the history match, the projections accurately predicted the subsequent leaching process evolution.

Figure 12 shows the expected cavern dimensions for a volume of around 10,000 m³. The shape of all the caverns was investigated in the first quarter of 1989 with sonar surveys. There was a good comparison between the predicted shapes and the actual shapes, allowing brine production to continue according to plan.

BLANKET LEVEL CONTROL

An essential requirement for a controlled brine production process using multistage leaching is the monitoring and maintenance of the blanket depth.

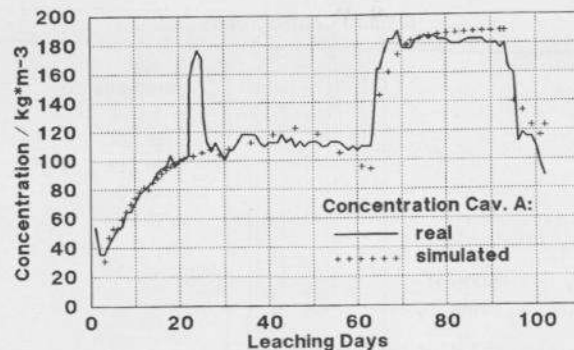


Fig. 10. Comparison of real and simulated brine concentration for Cavern A.

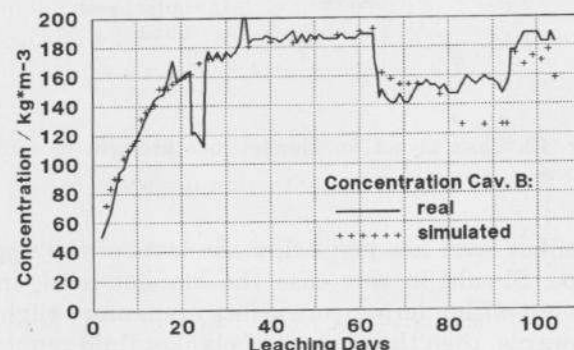


Fig. 11. Comparison of real and simulated brine concentration for Cavern B.

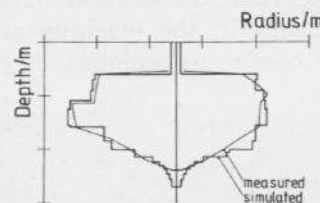


Fig. 12. Comparison of measured and simulated shape development.

From the various methods available, the technique utilising control tubes in the blanket annulus was selected. The basic layout of the tubes is shown in Fig. 13. The blanket level control tubes were fitted in a position, appropriate for the leaching concept, on the outer brine pipe. By establishing the blanket level between the ends of the control tubes it is possible to monitor the level of the blanket by taking fluid samples from the pipes at the head of the cavern.

The blanket/brine interface is correctly adjusted when the upper tube contains blanket fluid and the lower contains brine. The disadvantage of this technique for blanket level monitoring appears if the

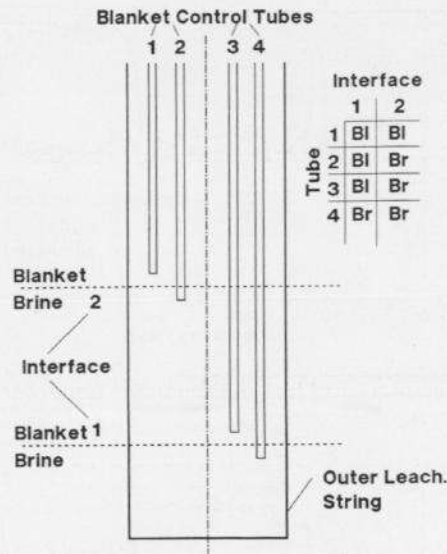


Fig. 13. Basic layout for blanket measurement by control tubes.

blanket level lies just below the level of the upper pipe. Should in this case the blanket level, in a cavern with a large roof surface area, move slightly upwards, then the amount of blanket fluid required to be injected is usually unrealistically large from technical and economic points of view.

On the positive side, an extra facility is gained in that this system can also be used to monitor friction loss development in the leaching strings — and therefore to check the amount of corrosion and

deposition within the pipe cross-sections. All in all, the blanket level monitoring system as described above has so far worked extremely well.

CONCLUSIONS

To date, the running of the operation at Pimai has shown that, on the strength of the investigations and planning that were carried out, the project achieved its targets and fulfilled the project predictions. Nevertheless, it is still necessary to carefully monitor and interpret the evolution of the leaching process. Information gained during the operation, in particular on the evolution of the salt concentration and the volume expansion, can, in conjunction with computer simulations, lead to further optimisation of the leaching process. This requires comprehensive documentation of all data relevant to the leaching process including sonar surveys.

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