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A Successful Exploitation Technology of Thin Multiple-Layer Halite Deposits

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ABSTRACT

The water fracture method, which has been awarded a prize at the National Conference on Science, is a successful exploitation technology of thin multiple-layer halite deposits. The method results from studying halite deposits in Hubei — an ore-bearing zone of 220 m, including 312 layers of salt, the thickest layer being 1.27 m and the thinnest only a few centimetres, with the highest ore grade being 99.8% NaCl, and the lowest 65% NaCl. The method is the exploitation of recovery brine by means of establishing a pair of qualified water-flood and brine recovery wells by fracturing, trough building, and production on the basis of identifying the target salt layer. This method applies the principle that water is incompressible, which means that the pressure can be passed. Within a well site of two or more wells, by water-flooding from one or more wells to pass the high pressure, the salt bed is channelled, the salt dissolved, and the channel is further reamed. As a result brine may be recovered from another well or wells connected with the water-flooded well. After 22 years of practice, the rate of success has reached 80%. In comparison with dry mining, resource exploitation output has doubled, raw material costs have decreased 2.5-fold, and as far as operating conditions are concerned, the workers are free from strenuous underground labour. Its success has promoted the development of the salt industry in China. This technology can also be used for exploitation of mirabilite, trona, etc. with similar geologic conditions.

INTRODUCTION

This paper outlines the geological characteristics and exploitation technology of thin multiple-layer halite deposits, gives an example, and compares economic effects. The successful exploitation technology of thin multiple-layer halite deposits has spread rapidly throughout Hubei Province, ending a history of non-production of well-salt in Hubei. Currently, Hubei produces 1.4 million tons of refined salt per year and has become one of the most important bases of inland China.

This technology has been recognized as one of the important national science and technology achievements, and was awarded a prize at the National Conference on Science, which was held in Beijing in March 1978.

GEOLOGICAL CHARACTERISTICS OF THIN MULTIPLE-LAYER HALITE DEPOSITS

The halite deposit in the Yunmeng-Yingcheng area in Hubei Province is a large-scale sedimentary deposit located in an inland salt lake basin of the Tertiary Cretaceous period. The strata of argillaceous silt rocks, anhydrocks (anhydrite rocks), calc-mirabilites and halite are revealed by geological drilling. The hanging wall and foot wall composed of anhydrocks, calc-mirabilites interstratified with multiple layer gangues and halite rocks, are geologically referred to as salt rock groups; the salt groups are separated from each other by the argillaceous silt rocks. All these salt groups constitute a large-scale sedimentary halite deposit. The salt groups are generally 2–6 m in thickness, the thickest being 14.67 m, and the thinnest 0.82 m. There are generally 8–10 salt layers within a salt group with a range of over 20 layers to as few as 5 layers, each of which is generally 0.2–0.4 m in thickness, with the thickest being 2.8 m, and the thinnest 0.002 m. The tenor of halite is generally about 80%, the best being 99.8%. Based on statistics from a particular drilling hole revealed in an ore-bearing section of 220 m (see Fig. 1), there are 23 salt groups, containing 312 salt beds, the thickest being 1.27 m and the thinnest 0.05 m; the highest tenor of ore is 99.8% and the lowest 65% (those lower than 65% will be named elsewhere). Lithological identification shows that the

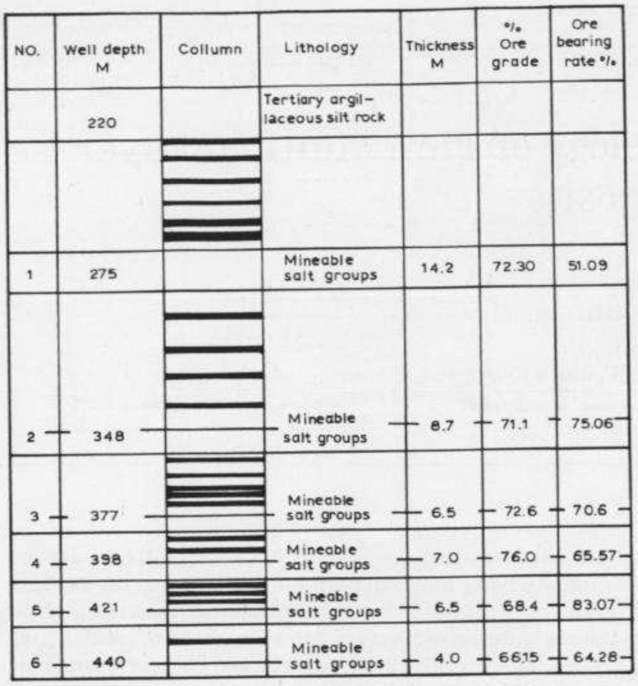

Fig. 1. Diagram of salt groups of ore-bearing section.

halite bed appears to be of coarse-grained intergrowth texture and tabular crystal; calc-mirabilite presents "rhomb" crystal of a prismatic and tabular texture; the anhydrite appears lumpy, spotty, striped and stratified. Cleavages are developed in the halite beds, the compression strength of halite beds equals 15 MPa, S.G. 2.24; the compression strength of calc-mirabilite beds is 20 MPa, S.G. 2.64, decreasing by 30% after hydrolysis, very easily separating the halite beds from the mirabilite beds. The anhydrite beds are solid with a compression strength of 46 MPa, S.G. 2.4; the argillaceous silt rock is an excellent aquifuge of which the compression strength is more than 50 MPa, S.G. 2.46. The ore deposits are characterized by: shallow burial of ores, usually exposed at a depth of 220 m (see Fig. 1) from the surface; wide distribution (100 km^2) throughout the area; simple monoclinal structures, dipping 2–4°, with stable rocks; and the absence of water beds in hydrogeological condition.

An outline of the exploitation technology

Pilot-scale solution and dry mining have both been carried out on the basis of careful study of the geological characteristics of thin multiple-layer halite deposits. A petroleum production method was introduced to the solution mining of rock salt. Petroleum can be recovered through a small-diameter channel well tube from the earth's surface to underground by controlling different types of pumps on the ground. The difference between petroleum and rock salt is that the former is liquid and the latter solid. Dry mining for rock salt was put into operation by using the original technique of coal exploitation with a series of vertical shafts, openings and faces (working faces), which requires many workers to operate the digging machinery underground. More than 10 years of practice of both solution and dry mining proved that the hydraulic fracturing of solution mining is considered to be a more successful method for the exploitation technology of thin multiple-layer halite deposits. Its success rate has reached 80% after 22 years of production in 203 wells in Yunmeng-Yingcheng, Hubei Province. This paper mainly deals with hydraulic fracturing.

Hydraulic fracturing is a force-type technology of connecting wells by applying the principle that water is incompressible. Within a site of two or more wells, high pressure can be develop between the wells in the salt bed. Water flow through the salt bed channel will dissolve salt and enlarge the channel and reduce the pressure, and brine is recovered. It is necessary to explain here that it is important to study the geological characteristics of thin multiple-layer halite deposits. For example, the compressive strength of the hanging wall and foot wall of the ore body is greater than that of the rock salt ore.

The halite deposits are of many layers, with well-developed cleavages in the halite beds. All these characteristics favour hydraulic fracturing as an exploitation technology.

EXAMPLE

(a) Column of an exploited salt group (Fig. 2)

The exploited bed shows that the thickness of the salt group is 8.37 m and that the hanging wall and foot wall of the ore body are all made up by massive lumpy anhydrites intercalated with 8 salt layers with an ore-bearing rate of 67.2%; the ore-body dips 4°. The analytical results of the halitic ores are listed in Table 1.

(b) Well pattern: spacing and siting (Fig. 3)

The well pairs are spaced along the dip of the ore-body set by set; within the first set there are two wells (No. 1 and No. 2) with an interval of 147 m; the distance between the sets is about 250 m.

(c) Well structure (Fig. 4 and Table 2)

The first, water-flooded well is drilled to the middle–lower part of the target salt layer with a 130 mm well bore. After drilling, a 114 × 6 mm technical

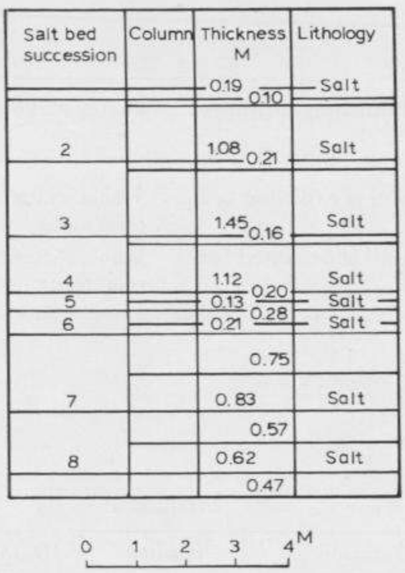

Fig. 2. Column of an exploited salt group.

TABLE 1

Analytical results of the halitic ores

NaCl (%)	Na_2SO_4 (%)	$MgSO_4$ (%)	$CaSO_4$ (%)
76.5	11.27	0.95	1.35

casing is put down. Petroleum cement is used for casing and cementing to be returned to the surface at one time. Three days after casing and cementing, the well must be drilled through the cement pillar (plug) and the target salt layer to the basal plane of the foot wall with a 90 mm well bore. The well is completed after the washing-out of the hole and testing of the pressure.

The other procedures for a brine recovery well, except for the initial drilling to the top of the target salt layer, are the same as those for a water-flooded well.

The precise depth of fracturing is established by core-drilling. In order to prevent Quaternary surface soil from collapsing, a surface soil casing of 168 × 7 mm is used, the ore section is laid bare, and the bottom of the well is plugged.

(d) Hydraulic fracturing and equipment

The hydraulic fracturing is divided into three stages: fracturing,trough building and production. The fracturing is the key to this technology. Fresh water is chosen as a fracturing liquid and is introduced to the water-flooded well at the very beginning. A few minutes after injection and pressurization, the pressure comes up to its peak value and the

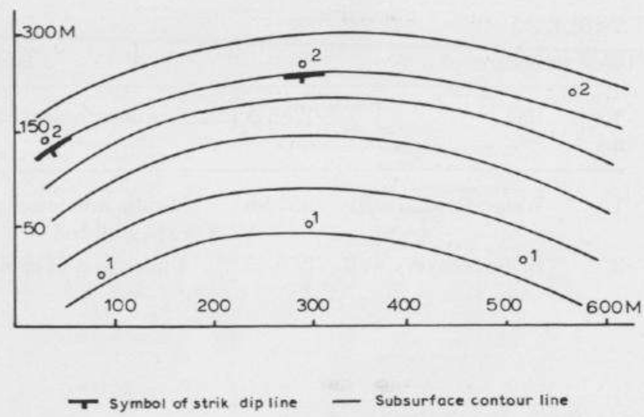

Fig. 3. Well pattern.

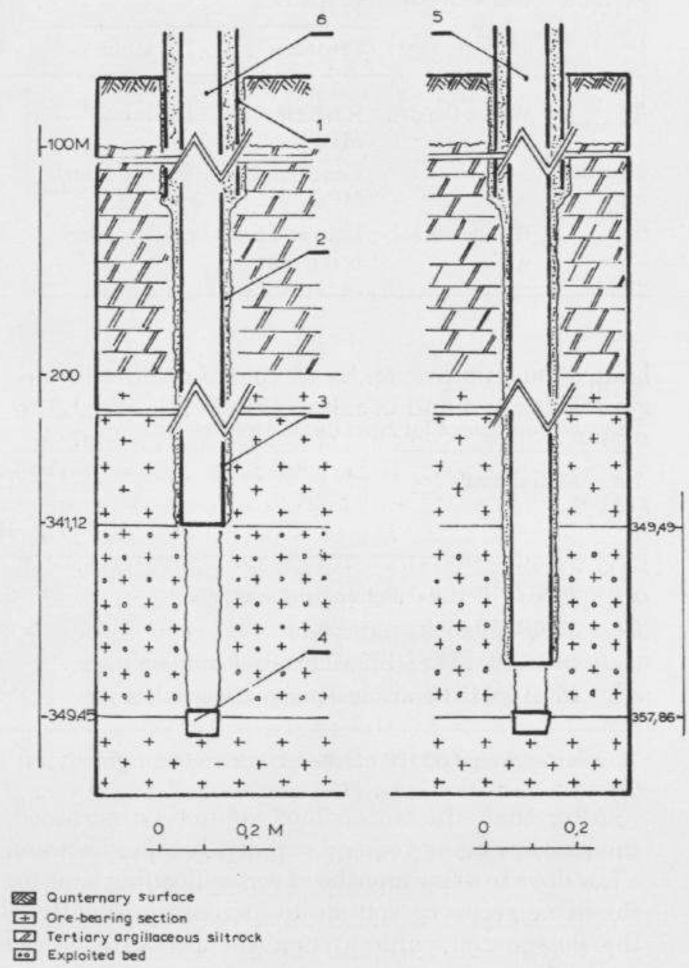

Fig. 4. Well structure.

salt bed begins to be fractured. When the pressure decreases (a few hours or days later) the connecting fissures begin to appear. When brine from the brine recovery well are seen, the pressure of the water-flooded well drops suddenly, marking the end of the fracture stage.

TABLE 2

Well structure

Well no.	Use	Well depth (m)	Site of technical casing	Site of finishing drilling of hole	Casing and cementing
1	Water-flooded well	357.86	Middle and lower parts of exploited bed	Foot wall of exploited bed	Whole sector casing and cementing
2	Brine recovery well	349.45	Upper part of exploited bed	Food wall of exploited bed	Whole sector casing and cementing

TABLE 3

Recorded data of Nos. 1 and 2 well group

Well no.	Use	Fracturing		Trough building		Production	
		Pressure	Duration	Pressure	Duration	Pressure	Duration
1	Water-flooded well	Rush time 12 MPa	1–3 min	5 MPa	72 h	2 MPa	Several years
		Continued 8 MPa	Several hours				
2	Brine recovery well	Dots and lines brine recovery being seen		Output of brine recovery increasing		Output of brine recovery reaching that stipulated	

TABLE 4

Selected equipment for Nos. 1 and 2 well group

No.	Equipment	Performance		Matched motor (kw)	Stage of use
		H (m)	Q (m^3/h)		
1	Type SNC-H300 engineering wagon	3000	9.12	118*	Fracturing
2	3W6B4 High-pressure pump	2000	7.2	55	Fracturing
3	DG36 50×10 Centrifugal pump of multiple stage	519	36	100	Trough building
4	150D 30×10 Centrifugal pump of multiple stage	270	120	155	Production

*Converted from 160 HP marked in the motor originally.

After that, the water-flood volume is increased, the passage being reamed rapidly. It takes between a few days to a few months of water-flooding time for the brine recovery volume to increase gradually to the designated value. When the pressure of the water-flooded well drops suddenly once again, the end of the trough building stage is reached. When the pressure of water-flooded well drops to normal production pressure, the output of brine recovery has reached the designated value. This indicates that a pair of wells is now ready for the production stage.

The recorded data of the Nos. 1 and 2 well group are listed in Table 3. According to the hydraulic fracture technology requirements, it is very important to choose suitable equipment at every stage. The selected equipment for Nos. 1 and 2 well group is given in Table 4.

(e) Several points for attention

(1) The target exploitation layer according to the present technique level must first be determined. Then the position contrast of the same layer for two or more wells must be carefully determined. On this basis alone can the well building engineering be completed or else "misplacement" will cause failure of fracturing.

(2) Well-building quality must be in strict accordance with the technique specifications, other-

TABLE 5

A comparison of economic benefits between the water fracture method and dry mining on thin multiple-layer halite deposits

No.	Item	Unit	Waterfrac method	Dry mining
1	Output of ore recovery	t/year	200,000	100,000
		Time	2	1
2	Capital work investment	RMB Y (Yuan)	3,670,000	12,400,000
		Time	1	3.3
3	Construction duration	Year	1	3
		Time	1	3
4	Brine cost	RNB Y/m^3 brine	1.15	2.88
		Time	1	2.5
5	Production processes (working procedures)	Procedure	3–5	34
		Time	1	8.5
6	Operator	Person	208	1540
		Time	1	7.4
7	Operating environment		Surface	Underground
8	Labour intensity		Less physical labour	Mainly physical labour

Source: Design Specification, 1970.

TABLE 6

Composition of brine

NaCl	Na_2SO_4	$CaSO_4$	$MgSO_4$
290 (g/l)	22.5 (g/l)	2 (g/l)	0.5 (g/l)

wise "cross trough" can also result in the failure of the technology.

(3) The fracturing stage is the most important stage of this exploitation technology. Before commencing the engineering, preparation must be fully made. After starting, the well must be flooded uninterruptedly with low drainage but high pressure in order to force the salt bed to be fractured and to prevent the fissures and passages from stoppage again, or "on and off" can lead to "all that has been achieved is spoiled" for this technology. The reason why this technology has achieved a high success rate is the careful study of the geological characteristics and the various aspects of construction and operation.

ECONOMIC BENEFITS

A comparison of economic benefits between the water fracture method and dry mining of the thin multiple-layer halite deposits is given in Table 5.

Proved by more than 20 years of practice, the water fracture method used for the exploitation of the thin multiple-layer halite deposits has been enjoyed great success. The quality of brine is shown in Table 6.

According to the actual amount in 1990, the brine output converted into refined salt averaged, per well pair, 30 thousand tons/year with the optimum of 42 thousand tons/year; the brine cost averaged RMB Yuan 4/m^3 (US$ 0.85/m^3) in 1990.

CONCLUSIONS

The water fracture method is a successful exploitation technique for thin multiple-layer halite deposits that is both reliable and economical. It has proved successful in practice in Hubei Province for more than 20 years. Nowadays, the technology has been further developed into a new method for the simultaneous exploitation of two layers of rock salt by dividing layer (Feng, 1993). With this success and the rapid spread of the technology, Hubei Province has made great progress in salt production. The output of refined salt has reached 1.4 million tons per year making Hubei one of the important salt bases of inland China. Hydraulic fracturing is widespread in China, and to date this technology has enabled five inland provinces to produce salt for the first time in their history, and has advanced the salt manufacturing industries of four other provinces. Because the technology greatly extended the solution mining areas of China's salt industry, it was awarded a prize at the National Conference on Science, and was recognized as an important national scientific and technological achievements. The technology is now being applied in the exploiting of mirabilite, trona, etc. with similar geological conditions.

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