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SUITABILITY OF LYONS SALT MINE FOR GASOLINE STORAGE

by

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Suitability of Lyons Salt Mine for Gasoline Storage

Object: To ascertain the capacity of the mine for storage of gasoline, the type of storage which might prove feasible, and incidentally, the permeability of the rock salt walls, floor, and ceiling to the gasoline fluid.

Summary: The mine was found to have a capacity equivalent to about one hundred 55,000-barrel tanks. The floor and ceiling of approximately 50% of the mine were found to have buckled and the floor of half the mine was covered with a debris of impure salt and shale to a depth of from 3 to 4 feet. Removal of this debris to the surface is not feasible. The cracked floor is permeable, as shown by water filtration under the mine pillars. The walls were found permeable at a distance of 10 feet from their exposed surface. The galleries rise with distance from the shaft with the result that the mine will be full at the shaft entrance before the floor will be covered at the extremities.

It is therefore believed that bulk storage introduced through the mine shaft is not feasible.

The possibility of dividing the mine into compartments was investigated. Because of the hazard of explosion, together with the quantity which would still be lost into the walls, this plan is also considered inadvisable.

Inasmuch as the mine is considered unsuitable from the leakage standpoint, no tests were made as to the chemical effect of the salt on the gasoline.

The mine is dry and has a constant temperature of about 78°F. It offers an ideal place for dry storage in packages, of a size not exceeding that of the shaft, 4' x 4' x 10'.

Description: The mine has been developed on the square pattern except in one corner where long tunnels exist. The total void space has the dimensions of approximately 3,000,000 sq. ft. with an average height of 10 ft., or approximately 30,000,000 cubic feet. This amounts to 5,350,000 barrels, or the equivalent of one hundred 55,000 barrel tanks.

The walls are entirely of rock salt and the limits of the mine have not been confined by geological formations, but by legal and economic reasons. The stratum mined is a 10 ft. section of a bed approximately 200 feet thick, which has numerous shale partings. The mined stratum is bounded above and below by such shale streaks, one of which lies approximately 6 inches below the floor of the mine, and another about 2 feet above the ceiling.

Large pillars of salt, approximately equal in volume to the void space, have been left within the mine. The walls of salt are banded at intervals of 2"-3" with dark streaks which are found regularly throughout the mine.

The floor and ceiling of the mine have both buckled along the planes of the nearest shale streaks. The floor is severely cracked and in areas where not actually buckled, sound reflections indicate the presence of cavities. The buckling is reported to take place over a period of about two years after removal of the salt. As a result of the cracking of the ceiling about one-half of the mine is filled to a depth of 3-4 feet with a debris composed of impure salt and shale, some stacked up, much lying loose in old abandoned sections of the mine. The buckling is due to flow of salt under pressure into the portion where the salt has been removed.

The mine has not encountered water.

The shaft passes through water zones, all above the 300 ft. level. During the history of the mine a considerable amount of water has entered the mine through the shaft. This water has been pumped from the pump under the shaft into abandoned parts of the mine. It has filtered through the floor, under the salt pillars, into the lowest levels, where it now stands over an area estimated to be 2,000 square feet, varying in depth up to 3 or 5 feet.

The mine is operated electrically with 250-volt direct current produced by a generator located in the main tunnel near the shaft. The main tunnels are lighted. Transporation is maintained by battery-operated train cars on rails.

A small portion of the older part of the mine (about 10%) is below the level of the shaft. The remainder rises with distance from the shaft, until at the present extremities a difference of about 10 feet elevation is attained. This would mean that the floor of the remote portion of the mine is at approximately the same elevation as the ceiling near the shaft.

Sampling: One sample was cut from the floor of the mine by drilling rows of 1 5/8" holes closely spaced and chiseling out the intervening salt. Its dimensions are 13"x 14" x 16". The floor at this point showed a four-inch shale streak below the salt.

Another sample was taken from the wall by making two horizontal cuts, each 2" high, 16 inches apart in a corner of one of the pillars at floor level. Rows of holes were then drilled at the extremities of the cuts, 4' and 7' from the corner, and when wedging failed to break off the section, 3 sticks of dynamite were placed in a hole drilled 3 feet above the desired block and exploded in the overburden, causing it to collapse onto the block with sufficient force to break it out. The sawed block broke into three pieces. The center one was brought to the laboratory for analysis. It was slightly irregular in shape, approximately 16" x 22" x 16".

Two holes were also drilled into the wall at a slope of 1:3 or an angle with the floor of 18°26'. These were drilled to a depth of 140" or a horizontal penetration of 132" (11 ft.).

Permeability tests:

Wall Sample: Two holes, 2" deep were drilled into the top, 1 hole 2" deep, 5" from the bottom and 1 hole, 2" deep, 12" from the bottom were drilled into the sides of the wall sample. Manometers filled with gasoline were attached. The gasoline passed into the sample.

Gasoline was poured into the holes drilled into the walls of the mine. Stoppers, interspersed with paraffin wax in one case, and plaster of Paris in the other, were placed at a point 2 feet from their bottom with a copper tube connecting the 2 ft. long chamber to a manometer on the wall. A total head of 100" of gasoline was placed against the formation.

In each case, the formation was found to be permeable.

Data and Calculations:

Gasoline, with a specific gravity of 0.75 and an absolute viscosity of 4.0 centipoises was injected into the samples and wall of the mine.

Sample calculation for K.

$$K = \frac{mu \; Q \log e \frac{r_e}{r_w}}{2 \pi t \; h \; \Delta p} = \text{permeability coefficient, millidarcies.}$$

where: mu = absolute viscosity, centipoises

r_e = drainage radius

r_w = well radius

Q = cc's of gasoline injected during test.

t = time, minutes, during test

h = thickness of hole, penetrated by exposed area of hole, during test.

Δp = difference in pressure across salt bed, atmospheres

$$K = \frac{1000 \times 4 \times 18.5 \times \log e\ 200}{2 \times \quad \times 1035 \times 61 \times .14} = 7.06 \text{ millidarcies}$$

TABLE I-Tests in the Mine*

Sample	Head of Gasoline Inches	Ave. Head Atmos. Inches	Quantity Prev. Inj. cc.	Quan. Inj. During Test cc.	Time Expired prior to test Minutes	Time expired during test seconds	K Millidarcies
Mine Wall #1	100-52	0.140	0	18.5	0	1035	7.06
"	100-52	0.140	20	18.5	20	1125	6.50
"	100-52	0.140	40	18.5	65	1380	5.30
"	100-52	0.140	350	18.5	500	1680	4.35
Mine Wall #2	100-92	0.164	100	3.5	1020	4800	0.25

* r_e = 132 inches;

r_w = 0.687 inches

h = 61 cm.

TABLE II-Laboratory Tests**

Sample	Head of Gasoline Inches	Ave. Head Atmos. Inches	Quantity Previously Injected cc.	Quantity Injected During Test cc.	Time expired During test seconds	K Millidarcies
Mine Wall #3	52-0	.048	0	20.1	Less than 7200	12.33
"	44-17	.056	25.0	10.8	2400	17.00
"	44-20	.059	36.0	9.6	1800	14.44
"	44-14	.054	46.0	12.0	2400	19.61
"	44-26	.065	58.0	7.2	1200	19.65
"	44-34½	.073	55.2	3.8	600	18.38
"	44-12	.052	59.0	12.8	2400	21.79
"	44-15½	.055	72	11.4	1800	24.36
"	44-10	.050	72	13.6	2400	23.98

Mine Wall #4	56-0	.052	0	21.6	Less than 7200	12.24
"	37-4	.038	25	13.2	2400	30.6
"	37-8½	.041	38.2	11.4	1800	32.70
"	37-3	.037	49.6	13.6	2400	12.04
Mine Wall #4(Cont.)	37-15	.048	63.2	8.8	1200	15.56
"	37-24½	.057	72.0	5.0	600	31.04
"	37-3	.037	77.0	13.6	2400	32.51
"	37-8	.042	90.6	11.6	1800	32.6
"	37-4	.038	90.6	13.2	2400	30.87
Mine Wall #5	42-0	.039	16.2	0	Less than 7200	12.24
Mine Wall #6	40-0	.037	15.4	0	192,800	0.51
Mine Floor Sample #2	18½-10	.026	0	3.4	2400	11.55
"	18½-12	.029	3.4	2.6	1800	10.57
"	18½-9½	.028	6.0	3.6	2400	11.36
"	18½-13	.029	9.6	2.2	1200	13.39
"	18½-15½	.031	11.8	1.2	600	13.69
"	18½-7½	.024	13.0	4.4	2400	16.20
"	18½-10	.027	17.4	3.4	1800	14.85
"	18½-8½	.025	17.4	4.0	2400	14.13
Mine Floor Sample #1	42-41	.77	0	0.4	2400	0.05
"	42-41½	.77	0.4	0.2	1800	0.05

"	42-41½	.77	0.6	0.2	2400	0.05
"	42-41 3/4	.77	0.8	0.1	1200	0.05
"	42-41 3/4	.77	0.9	0.1	600	0.05
"	42-41½	.77	1.0	0.2	2400	0.05
"	42-41½	.77	1.2	0.2	1800	0.05
"	42-41½	.77	1.2	0.2	2400	0.05

** r_e = 6 inches; r_w = 0.4687 inches; h = 7.65 cm.

Mine Wall #1 = Hole drilled in wall of mine, stoppered with cork and paraffin.

Mine Wall #2 = Hole drilled in wall of mine, stoppered with cork and Plaster of Paris.

Mine Wall #3 = Hole drilled in top of block removed from mine.

Mine Wall #4 = " " " " " " " " "

Mine Wall #5 = Hole drilled in side of block 12" above bottom.

Mine Wall #6 = Hole drilled in side of block 5" above bottom.

Mine Floor #1 = Hole drilled into shale from top of block.

Mine Floor #2 = Hole drilled into shale from side of block.

Conclusions: The mine was investigated with three possibilities of usage in mind, (1) Conversion of entire mine to bulk storage space for gasoline, (2) Division of mine into sections, some of which might be used for bulk storage of gasoline, and (3) storage space for containers of gasoline, explosives, and other miscellaneous items required as a reserve in time of war.

(1) The mine is not suitable for bulk storage of gasoline.

The floor levels are such that only part of the space would be filled when the ceiling of the main tunnel was reached. The floors and ceiling have both buckled, leaving a considerable amount of space from which the gasoline could probably never be recovered. The walls are permeable to gasoline under its own pressure head.

(2) The mine is not suitable for bulk storage in compartments.

The mine might be divided into compartments, each to be operated in the same manner as a tank on the surface. This would have the advantages of conservation of steel, protection from aircraft, and negligible evaporation due to the constant temperature.

The debris could be moved to other sections of the mine. It cannot be disposed of at the surface because of the brine which would ensue.

Water could be introduced to prevent filtration through the floor. This would necessitate a distribution system of both gasoline and water lines underground, which entails a hazard of explosion, and a serious labor problem; or the drilling of wells from the surface into each compartment.

The loss because of the permeability of the walls would need to be considered.

The available space would, at best, be reduced by about half, or to an equivalent of about fifty 55,000 barrel tanks.

(3) The mine is an excellent place for the storage of packages or containers.

The mine is dry and at a constant temperature of 78° F. The size of the package would be limited to the size of the shafts, approximately 4' x 4' x 10'.

Submitted by:

/signed/ John I. Moore

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March 30, 1942

THE UNIVERSITY OF KANSAS
STATE GEOLOGICAL SURVEY
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Supplement to report on

SUITABILITY OF LYONS SALT MINE

for Gasoline Storage

In an effort to estimate the quantity of gasoline that would be lost through bulk storage in the mine, several assumptions have been made and the loss calculated.

The permeability tests showed a horizontal permeability of 13.21 millidarcys in the shale below the salt bed, but only 0.5 millidarcy vertically; this indicated there is little danger of seepage through the floor until sufficient time has elapsed to permit the shale to become softened by contact with the gasoline. This time was not determined.

To completely fill the mine would require a head of gasoline in the shaft approximately ten feet above the ceiling. No sample was taken from the ceiling for permeability tests. In the older, abandoned sections of the mine the ceiling has parted along the shale beds in the same manner as the buckling of the floor, exposing the shale to any gasoline stored. The same consideration would probably hold for the ceiling as for the floor, except for a much less applied pressure.

The permeability of the salt wall near its exposed surface averaged 14.35 millidarcys, but eleven feet within the wall, averaged 5.80 millidarcys. The latter figure is believed to be more representative of the entire bed.

There does not appear to be a satisfactory method of determining the porosity of the salt, due to its tendency to crack when handled and expand on removal from the mine walls.

Assumptions:

Porosity	= 2%
Perimeter of outer wall of mine	= 8,000 ft.
Height of mined area	= 10 feet
Volume of pillars	= 10,000,000 cu. ft.
Permeability of walls	= 5.80 millidarcys
Penetration of gasoline	= 20 feet

Calculations:

$$\text{Rate of loss (Bbls./day)} = \frac{.55 \times 2\pi \, t \, k \, \Delta p}{\mu \ln \frac{re}{rw}}$$

$$= \frac{.55 \times 6.2832 \times 304.8 \times 5.80 \times 0.22184}{4.0 \times 0.006770} = 21.772 \text{ Bbls./day}$$

Volume of Void space in 20 ft. wide strip around mine

$$= \{.02\} \{ (8000 \times 10 \times 20) = (4 \times 10 \times 20 \times 20) \} = 32320 \text{ cu. ft.}$$

or 5755 Bbls.

The gasoline would fill this space in $\frac{5755}{21.772}$ days or 6.28 hours. It would then continue to penetrate the remainder of the salt bed at a gradually decreasing rate. The total loss is limited only by the extent of the salt bed.

In the event the project should still be considered feasible, the following investigation should be conducted:

(1) A column of gasoline, dyed with a material not absorbed by salt, should be placed in contact with the entire wall for an extended period of time. The wall should then be removed and the rate of penetration and quantity lost determined. Such a test would require elaborate equipment, and would prove relatively expensive in time, labor, and materials.

(2) The chemical effect of the salt on the specific gasoline to be stored should be determined.

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