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MEETING PAPER


UNDERGROUND STORAGE IN THIN SALT LAYERS ON TEESSIDE


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Manchester, UK
October 1982

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## 1 INTRODUCTION

ICI operates two underground storage sites on Teesside in the North East of England. These sites are located at Saltholme to the North of the River Tees, near ICI's North Tees Works, and within ICI's Wilton Works to the South of the River Tees.

In this paper I shall seek to trace the evolution of underground storage operations at these sites with particular reference to the development of certain key principles for storage operations using brine displacement in the relatively thin salt layers that exist on Teesside. I shall also give an indication of the type of underground storage facilities used and the range of products stored

The rock strata under the ICI land at Saltholme to the North of the River Tees includes a layer of salt at a depth of round about 340m which varies in thickness between 27m and 40m. This salt layer is sandwiched between layers of marl and anhydrite. Overlying this there is a water bearing layer of sandstone stretching from 30m down to 270m below the surface.

ICI extracts salt from the Saltholme brinefield for chemical manufacture, and solution mining techniques have been developed so as to form discrete brine filled cavities of a size, shape and spacing designed to prevent subsidence of overlying formations. Over a hundred of these cavities have now been formed, varying in final leached volume from 10,000 $m^3$ to 100,000 $m^3$ capacity.

## 2 COMMENCEMENT OF STORAGE OPERATIONS AT SALTHOLME

The first salt cavity in this area to be used for underground storage was cavity No53, developed by ICI specifically for use by the Northern Gas Board for Town's Gas storage. A detailed description of this project was published in 1959 by Mr E Crowther, then Chairman of the Northern Gas Board, in the Transactions of the Institute of Gas Engineers, so my reference to it in this paper will be brief, but necessary, since it was the starting point. The cavity was intended to operate by pressure variation rather than brine displacement, and the minimum pressure required approached atmospheric, so it was decided that to avoid any risk of subsidence the solution mined volume should be limited to 10,000 $m^3$. Drilling commenced in January 1957, encountering 35 m of salt at 359 m below the surface. A 16" od surface drift casing was installed down to 38m, and an 11 3/4" od intermediate casing extended to the bottom of the Sandstone aquifer. The borehole was lined with a 7 5/8" od final cemented casing. Solution mining was completed at the end of January 1959, the salt extraction rate being governed by ICI's requirements, and the cavity was left full of brine The brine was then displaced via a 3" od brine dip pipe by Town's Gas, the Town's Gas being introduced into the cavity through the annulus between the 7 5/8" and 3" pipes. When brine displacement was complete, the brine valve at the well head was isolated, and variable pressure storage operation began.

The material stored in the cavity was subsequently changed to natural gas, and two more cavities, Nos 89 and 90 have since been developed for Northern Gas for this duty, and commissioned in 1973 and 1974 respectively. A fourth cavity, No 132, is now being prepared for natural gas storage. With the operating pressure now limited to between 45 and 25 bar, larger cavity volumes have been permitted in these more recent cavities than in the original No 53 cavity.

## 3 THE FIRST PROPYLENE STORAGE CAVITY

It was realised that the depth of the salt strata also permitted the storage of liquefied petroleum gas under pressure, using brine displacement.

The underground storage of liquid propylene by ICI in a salt cavity commenced in 1960, ICI having first studied the effect of storing propylene in contact with rock salt and finding no significant change in composition or behaviour. The need for bulk storage had arisen first to accommodate day to day surpluses in production due to frequent shutdowns of the consuming plant and second because of a temporary excess of production capacity. The original plan was to develop a small cavity of up to 4000 $m^3$ capacity to accommodate the daily surpluses only, but this scheme was eventually abandoned in favour of using the existing No 38 salt cavity which had been formed in the course of brine winning operations. This existing cavity had a capacity of about 30,000 $m^3$, large enough to accommodate some of the excess production as well as day to day surpluses. The cavity was an oblate spheroid 73 m in diameter but with a height of only 15 m.

### 3.1 Equipping the Cavity for Storage

Cavity 38 had been first drilled in 1954 and fitted with a 7 5/8" od cemented casing down to 329 m, penetrating the salt layer by less than 2m. An 11 3/4" od outer casing through the surface drift had been cemented in during drilling, down to 34m, but in common with other brinewinning cavities no additional intermediate casing had been installed through the sandstone aquifer. Careful consideration was therefore given to the adequacy of the single 7 5/8" od casing for storage operations, because of the risk of propylene escape into the aquifer through external corrosion of the casing even though it was protected by the cement grouting. It was finally decided that a single casing was acceptable for a limited future life and that it should then be relined by cementing in an additional inner casing tube.

The original 3" od brine dip pipe and well-head used for brine winning were replaced by a new 5" od dip pipe down to 339 m, terminating 5 m above the base of the cavity to ensure it was clear of solution mining debris. The brine string tubes were of conventional API standards with tapered screw threads. A thread sealing compound was used in making the joints.

Access to the cavity for brine movements was thus provided via the 5" od dip pipe, with propylene being injected or withdrawn via the annulus between the 5" and 7 5/8" diameter tubes.

The hydrostatic head of brine in the cavity was about 40 bar, sufficient to maintain propylene as a liquid at cavity temperature, and to distribute it as liquid in the overground pipe system at about 25 bar. The casing and brine tube diameters were adequate for the 20 $m^3$/h maximum liquid flow rates then required. After installing the new brine string, nitrogen pressure was applied to the annulus sufficient to lower the brine interface to cavity roof level. This test revealed leaks in the well-head internals which were dealt with. The cavity itself and the cemented casing had already been proved pressure tight by being left standing under air pressure after brine winning ceased.

Since the brine in the cavity had been in contact with air it was circulated through an atmospheric pressure tank at the surface to disengage dissolved air before propylene was introduced.

3.2 The Propylene and Brine Systems

Cavity 38 was conveniently located only some 30 m from an existing 4" diameter propylene link line supplying plants in the Billingham factory from the naphtha cracker at Wilton. A branch connection was made to the well-head with a catchpot and level trip designed to isolate the cavity automatically in the unlikely event of brine carry-over. The link line working pressure was raised to around 25 bar commensurate with the propylene well head pressure in the cavity and a low pressure trip was included in the system.

It was realised that if propylene entered the brine dip pipe it would rise to the surface and over-pressure the brine system. A catch pot was therefore installed in the brine main at the well head with a level detector so that the presence of a propylene/brine interface would be detected and would automatically trip a safety shut-off valve in the brine main and give audible and visible alarm. In order to facilitate the operation of the catch pot if propylene breakthrough into the central dip pipe occurred as a result of overfilling the cavity, a slot was cut in the bottom 6" of the dip pipe so that if the propylene/brine interface reached this depth the initial breakthrough of propylene would be in relatively small amounts enabling the automatic alarm and shut-down system to react most effectively. But in the unlikely event of damage occurring to the brine tube, the catch pot was still intended to provide the necessary protection against propylene breakthrough into the overground brine system.

During storage operations the level of the propylene/brine interface above the end of the brine dip pipe was checked periodically by means of a pneumercator device. The brine dip pipe was isolated from the brine main and a small cross over valve opened into the propylene annulus, equalising the brine levels in the cavity and dip pipe whilst maintaining the cavity pressure constant. The cross over valve was then closed and the propylene pressure in the dip pipe was increased by means of a small metering pump until propylene emerged from the bottom of the dip pipe. The pressure difference between the dip pipe and the annulus was thus a measure of the level of the interface in the cavity above the end of the dip pipe. The propylene was subsequently displaced from the dip pipe with compressed nitrogen, taking care that the nitrogen did not break through into the cavity, and the nitrogen was then displaced back up the brine tube to atmosphere with brine, restoring the cavity to normal operation. Finally the volume of propylene in the cavity was calculated from the cavity calibration curve and compared with the integrating flowmeter measuring propylene movements in and out of the cavity.

The risk of propylene hydrate formation was examined carefully. It was concluded that there was no risk of hydrate forming in the conditions prevailing in the cavity, but hydrate could theoretically form at temperatures below 2°C in the well head and above ground pipework. In the event no special precautions against propylene hydrate formation were taken and none have since been found necessary.

No overground brine reservoir was installed at this stage. Brine displaced from the cavity when propylene was injected was accepted back into the fresh brine supply for chemical manufacture, since the amount of dissolved hydrocarbon in brine leaving the cavity estimated at not more than 25 ppm, would be adequately diluted by the fresh brine. During propylene withdrawal from the cavity, displacement brine was taken from the fresh brine supply for chemical manufacture.

I have described the use of cavity No 38 for propylene storage in some detail because it was our first brine displacement storage cavity, and it established some of the principles which have been the basis of subsequent storage operations in thin salt layers, though we have subsequently improved the techniques.

## 4 IMPROVEMENTS IN TECHNIQUE

Cavity No38 continued in use for propylene storage until 1969, when it was taken out of service and the borehole relined as originally planned. The cavity was subsequently brought back into use temporarily for LPG storage.

### 4.1 Cavity Shape

Meanwhile propylene storage was transferred to cavity No43, since it was obvious that the very flat shape of cavity 38 was less than desirable. Since by then the use of cavities for storage had become an established practice, the need to produce cavities of more suitable shape for storage purposes also became a feature of brine winning operations, and when such a cavity became available the transfer was made. Cavity 43 had a height of 40 m compared with only 15 m in cavity 38. Both cavities had about the same diameter of around 73 m. One problem with cavity 43 was an interconnection with the adjacent unused cavity No 42, at 35 m below roof level, and in view of this the volume of cavity 43 used for propylene storage was restricted to 45,000m out of a total volume of 80,000 $m^3$ to ensure that the propylene brine interface always remained above the level at which break through into cavity 42 would occur.

### 4.2 Second Borehole

In order to provide higher movement rates than would have been possible via the original 8 5/8" od final cemented casing of the borehole used for brining, a second borehole was drilled into the cavity with a 10 3/4 " od final cemented casing, for product movement. This also made it possible to reline the original brining borehole with a 5 1/2 " od cemented casing, thus eliminating any risk of leakage through the original casing tube.

### 4.3 Pressure Control

A more sophisticated system of automatic protection had been developed during the 10 years experience we had acquired by 1970 on underground storage. Provision was included to isolate the cavity automatically in the event of any deviation in pressure outside a predetermined range. Our practice was to ensure that the cavity was never subjected to pressure variations during storage in excess of what it had experienced during solution mining. Storage operations were arranged so that the pressure at the cavity roof should never fall below the static head of brine and never exceed the static head by more than 40 psi. Bearing in mind that the static pressure on the cavity roof varied by 30 psi according to whether the propylene brine interface was at its highest position near the cavity roof or at its lowest position in the cavity, one can easily see that this did not leave much allowance for frictional pressure drop through the brine string and overground brine system when filling the cavity with propylene, and this illustrates the careful operational control required. Relief valves were installed in the brine main at the well head as an additional precaution against over pressuring the cavity, but these were not very satisfactory as they did not allow for the variation in permissible well head pressure as the interface level in the cavity varied, and also of course they would have made it more difficult to prevent propylene escaping from the system in the event of overfilling or failure of the brine dip pipe, and in our more recent systems no brine relief valves have been fitted.

4.4 Interface Level Measurement

Measurement of the interface level by means of a pneumercator device could now be made without interfering with product movements, using a 3" od dip pipe in the original brinewinning borehole.
Arrangements were also made to check the level of the propylene brine interface in the cavity periodically by means of a radioactive probe lowered down the 7" od dip pipe. This probe comprised a gamma radiation source and a detector measuring the strength of the reflected signal which depends on the electron density of the surrounding medium. It was sufficiently sensitive to detect the propylene brine interface through the wall of the brine dip pipe.
As a last resort provision was made to isolate the cavity automatically if any propylene/brine interface was detected outside predetermined levels in the catch pots connected to the propylene and brine pipelines at the well head.

4.5 Overground Brine Reservoir

By the time cavity 43 was commissioned other underground storage developments which I will also briefly describe in this paper had justified the installation of an overground brine reservoir and brine distribution system, and cavity 43 was connected to this system.
Use of an overground reservoir exposing the brine to dilution by rainwater introduced a further key principle for storage operations in thin salt layers, namely to maintain careful control of the strength of the brine used for displacement, since the cavities leave very little margin for unintentional additional leaching and the frequent product movements make controlled cavity enlargement impossible to achieve. Weak brine was therefore periodically skimmed off from the reservoir surface and replaced with saturated brine.

5 THE PRESENT STORAGE SYSTEM AT SALTHOLME

Cavity 43 continued in operation until 1979, when the requirement for a cavity capable of receiving and discharging product at much higher rates necessitated the change over to cavity No74, a discrete cavity of good shape which had just been released from brine winning. A second borehole was drilled into cavity 74 and fitted with a 13 3/8 " od final cemented casing and 9 5/8 " od brine tube, suitable for propylene movements up to 125 te/hr. The 10 3/4 " od casing of the original brining borehole was relined with a 7 " od cemented casing.

5.1 Principles of Storage Operation

The principles of storage operation established in cavities 38 and 43 are continued and developed in cavity 74 as follows:-

(i) Pressure Control
The original brining borehole is used as an instrument borehole. It is fitted with concentric 4 1/2" and 1.9" od dip pipes, The outer annulus between the 4 1/2" dip pipes and the 7" od casing is used to give a direct measurement of cavity pressure and instrumented to give an alarm and then to isolate the cavity automatically in the event of pressure variation either above or below preset limits. This is backed up by monitoring the pressure in the overground propylene and brine systems.

(ii) Overfill Protection
The end of the 1.9" od brine tube in the instrument borehole is set 1 metre above the end of the 9 5/8" brine tube used for product movement. In this way before the interface could reach the end of the 9 5/8" brine tube and cause propylene to break through into the brine system, it would first have to enter the end of the 1.9" dip pipe and raise the pressure in this pipe. Instrumentation has been provided so that any such increase in pressure in the 1.9" dip pipe would automatically isolate the cavity before overfilling could occur. This is backed up by level trips on the catch pots in the brine and propylene pipelines at the well head which also protect the brine system against dip pipe failure

(iii) Interface level measurement
The annulus between the 1.9" od and 4 1/2" od dip pipes in the instrument borehole is used for measuring the level of the interface by means of a pneumercator device as installed in cavities 38 and 43. Because the dip pipe used is separate from the product movement dip pipe, as in cavity 43, pneumercator measurements do not interfere with product movements. The level of the interface is also checked periodicaly using the radioactive probe lowered down the 9 5/8" od brine tube.

(iv) Brine strength control
Reservoir brine strengths continue to be monitored and controlled regularly.

5.2 Temperature Control

A further principle relating to underground storage operations in thin salt layers which has not been mentioned so far is the need to avoid too large a temperature gradient across the remaining salt forming the roof of the cavity. The brine displacement cavities, which were originally formed as a result of brine winning activities, and are now used for storage, are made for both purposes as large as possible within the confines of the thin salt layer available. As a result there remains only about 1 metre thickness of salt forming the roof of the cavity and separating it from overlying rock strata, and any cracks caused by temperature changes in the salt might provide leakage paths from the cavity into overlying strata, and might also result in roof falls. The need to control the temperature of the product stored in contact with the cavity roof is thus a very important requirement, much more so than in salt caverns which are surrounded by many metres of salt thickness. Our storage procedures are intended to ensure that the material stored in contact with the cavity roof does not vary by more than ± 3°C from the temperature of the surrounding salt strata. Fortunately the borehole with its central brine tube acts as a convenient heat exchanger, particularly since for the products we store the volume of brine displaced has a much higher heat capacity than the equivalent volume of product introduced, so that within the normal range of ambient temperature incoming product arrives at the cavity roof very close to the temperature at which brine leaves the cavity. A problem arises however in our higher movement rate cavities where large amounts of cold brine could be introduced into the cavities in winter. This cold brine would be insulated from the cavity roof by the layer of stored product so it would not immediately constitute a hazard but when subsequently more product is introduced into the cavity, heat exchange between the product entering and the cold brine leaving results in the product coming into contact with the cavity roof at too low a temperature. Where this risk is likely to occur we have installed brine heaters to control the temperature at which brine enters the cavity. Cavity temperatures are monitored by means of a temperature sensitive oscillator incorporated in the probe used for interface measurements. By this means the change in temperature of the brine can be measured as it moves down the brine tube, and hence knowing the temperature at which product emerges at the well head the temperature of product in the roof space can be determined.

The so-called "dry" cavities, such as the natural gas cavities mentioned earlier, which operate by pressure variation, must necessarily be smaller (in order to withstand these pressure changes) than the brine displacement cavities in which the pressure remains fairly constant, and in forming these dry cavities several metres of salt are left above the cavity roof. This greater salt thickness also permits the associated temperature changes to be tolerated, as gas is withdrawn from the cavity, provided the withdrawal rate and the pressure range are kept within prescribed limits.

### 5.3 Range of Products Stored

The principles described for the underground storage of propylene have been applied to the storage of other products and raw materials in brine cavities at Saltholme. A major development occurred in 1966 when several cavities were commissioned for the storage of crude oil and refinery products for Phillips Imperial Petroleum, the jointly owned subsidiary of ICI and Phillips Petroleum Company. It was also at this stage that the first overground brine reservoir and associated brine distribution system were installed. Some of the refinery products were distributed to cavity storage at too high a temperature, and to enable the temperature constraints to be met brine/product heat exchangers were installed at well heads where necessary to supplement the heat exchange afforded in the boreholes. These additional heat exchangers have proved somewhat less than successful, on one occasion being a source of oil leakage into the brine system. This is particularly undesirable where a common brine system serves several different cavities. A better arrangement is to eliminate excessive product temperature variation at source, and this is what we now seek to do in our more recent storage systems.

In 1971 further cavities were commissioned for storing hydrogen. Operation by brine displacement was chosen in preference to the variable pressure option in order to make the most effect use of the available cavity volumes. A second borehole was drilled into each cavity and fitted with a 16" od final cemented casing and a 10 3/4" od brine tube, permitting flow rates of up to some 400,000 SCFH of gas per cavity. Extensions to the brine distribution system were made to accommodate these cavities and further extensions to the brine reservoirs and distribution systems have since been made to keep pace with storage development

The present underground storage system at Saltholme includes facilities for storing crude oil, gas oil, naphtha, natural gas, hydrogen, nitrogen, propylene and LPG. The individual cavities range in size from 10,000 $m^3$ to 90,000 $m^3$.

## 6 UNDERGROUND STORAGE AT WILTON

In addition to the cavity developments which have been described at Saltholme, ICI have also developed storage cavities in their Wilton factory to the South of the River Tees. Here the salt layer is of about the same thickness as at Saltholme, but at a much greater depth, approximately 647 m below the surface. Rock formations overlying the salt include Keuper Marl from 109 m down to 312 m, and Bunter Sandstone from 312 m down to 574 m. A significant feature of the Wilton salt layer for ICI is that it is at sufficient depth to store ethylene at above its critical pressure under the static head of brine, so that about three times as much ethylene can be stored per unit volume in a Wilton cavity as in an equivalent Saltholme cavity, and since both ethylene producing and ethylene consuming plants were already located at Wilton, the advantages of underground storage of ethylene at Wilton justified the solution mining of cavities there specifically for this purpose. Once the precedent had been established, other cavities for butenes and nitrogen as well as ethylene have also been developed at Wilton together with their associated overground brine reservoirs.

Since the Wilton cavities were developed solely for storage purposes, the solution mining boreholes were designed to enable the eventual product movement rate to be achieved without the need to drill a second borehole. In the earlier cavities 9 5/8" od final cemented casings were used, but more recent cavities have 13 3/8" od casings. In addition to the surface drift casing, all the boreholes have an intermediate casing cemented to the bottom of the Keuper Marl. In order to provide the same degree of protection against product break-through into the brine system that we have in the Saltholme cavities, a 9 5/8" od protection tube is installed concentric with the 7" od brine tube. The protection tube terminates slightly above the end of the brine tube so that if the brine/ethylene interface reaches too low a level, ethylene would break-through first into the static brine annulus between the protection tube and the brine tube and activate the automatic shutdown system. Also the protection tube safeguards the brine system against failure of the brine tube. It does however decrease the heat transfer between brine and ethylene in the borehole and makes cavity temperature control more difficult.

The brine system is additionally protected by surface catch pots fitted with level trips, as at Saltholme, and these also serve to disengage dissolved ethylene before brine is returned to the reservoir.

Ethylene hydrate forms below 18°C at cavity pressures. Fortunately the strata temperature is several degrees higher so there is no risk of hydrate formation in the cavities themselves. The incoming brine is heated and the overground ethylene pipelines are steam traced in order to avoid hydrate formation in the borehole and overground systems.

Our most recent Wilton cavities have been drilled with separate product movement and instrument boreholes in order to maximise product movement rates without sacrificing instrumentation.

## 7 ACKNOWLEDGEMENT

In conclusion I would like to thank Imperial Chemical Industries PLC for allowing me to present this paper, and Dr P B McFarlane for his helpful comments during its preparation.