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THE USE OF INERT GAS AS CUSHION GAS IN UNDERGROUND STORAGE: PRACTICAL AND ECONOMIC ISSUES

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ABSTRACT

The 395 underground natural gas storage fields in the United States are operated by both transmission and distribution companies as an integral part of the gas industry's delivery system. Base (cushion) gas is required to maintain storage reservoir volume and pressure to ensure adequate deliverability.

Base gas is a major investment cost for new storage field development. An inert gas, such as nitrogen, that is less expensive than natural gas can be used to fill all or part of the base gas requirement and yield significant savings in the cost of storage field development.

Inert base gas use, tested originally in France, should not dilute the pipeline quality of natural gas withdrawn from storage. Therefore, the key technical issue is the degree to which natural and inert gases mix in the storage reservoir. The nature of the rock pore spaces that comprise storage fields inhibits the mixing process. A systematic planning approach has been developed to ensure that there are no long-term operating problems with storage fields containing inert base gas. The first field test of inert base gas technology in the U.S. is being planned.

The use of inert base gas is a promising technique with the potential to significantly reduce storage investment costs.

THE USE OF INERT GAS AS CUSHION GAS IN UNDERGROUND STORAGE: PRACTICAL AND ECONOMIC ISSUES

INTRODUCTION

Background

Underground storage of natural gas is used extensively by both the transmission and distribution segments of the U.S. gas industry to balance a variable demand with a relatively fixed pipeline capacity. There are currently 395 storage reservoirs operated by 92 companies in 26 states. These reservoirs have a total capacity of over 7.7 TCF and, in 1989, delivered over 2.4 TCF of natural gas to consumers [1].

Of the 6.1 TCF of natural gas stored in U.S. storage fields on December 31, 1989, 3.6 TCF was cushion (base) gas [1]. Base gas is that portion of inventory that remains in storage fields to maintain reservoir volume and pressure to assure adequate deliverability. Depending on the reservoir in question, base gas can represent as little as 15% or as much as 75% of total inventory. For U.S. storage fields as a whole, base gas represents over half of total developed storage capacity.

Recent trends in natural gas pricing and market sizes have affected overall industry operations, including underground storage. Figure 1 shows average wellhead gas prices [2] and the number of underground storage fields [1] from 1960 to 1989. Note that the price increases beginning in the mid-1970's correlate well with a drop in the rate of new storage field development. The current number of storage fields (395) is actually lower than the maximum (412) reached in 1983.

The importance of underground storage in meeting market demands, however, has continued to increase in spite of a total decline in natural gas consumed. Figure 2 shows both total gas consumption and gas withdrawn from storage (as a measure of storage field utilization) from 1960 to 1989 [2]. Although total gas consumption and the rate of storage field development have declined since the mid-1970's, the annual volumes of gas withdrawn from storage have continued to rise. Figures 3 and 4 [2] demonstrate the reasons for increasing storage field utilization. Figure 3 shows the contributions of the major market categories (residential, commercial, industrial, and electricity generation) to total gas consumption. The most temperature-sensitive portions of the total market (residential and commercial) have remained relatively constant since the mid-1970's. Figure 4 shows combined residential/commercial consumption in terms of both total volume and percent of total consumption. In view of these trends, it is not surprising that underground storage is increasingly important to the industry's ability to match supply and demand.

Growth in underground gas storage will be required for the following reasons:

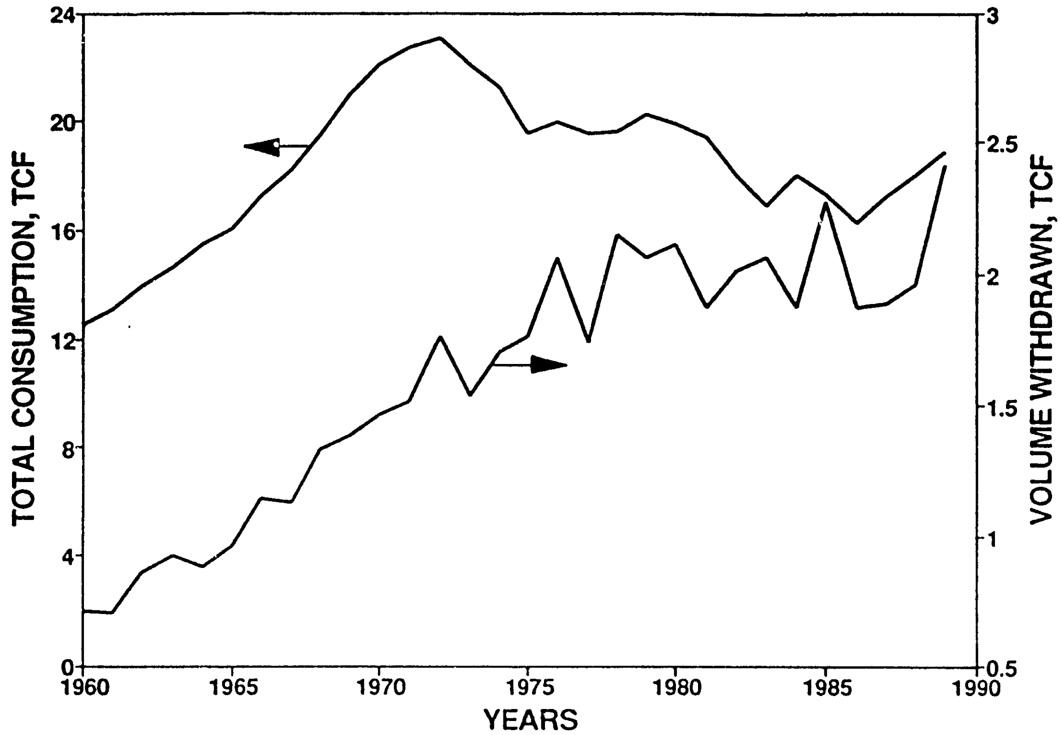

Figure 1. NUMBER OF U.S. STORAGE FIELDS AND WELLHEAD GAS PRICE -- 1960 TO 1989

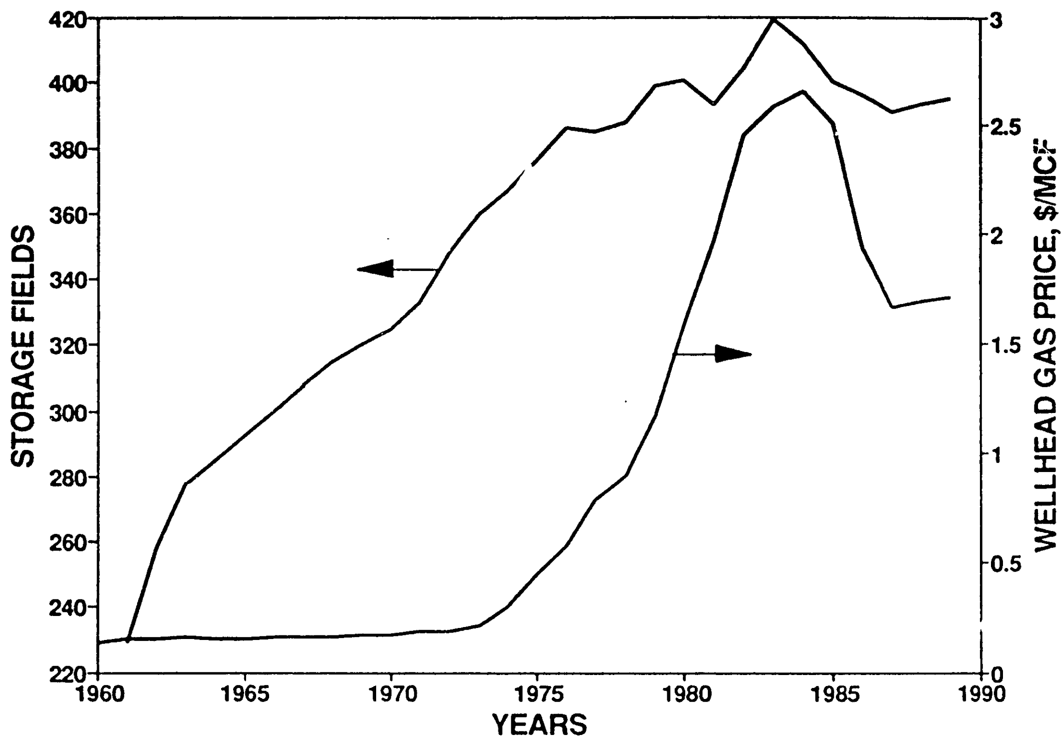

Figure 2. TOTAL GAS CONSUMPTION AND VOLUME OF GAS WITHDRAWN FROM STORAGE -- 1960 TO 1989

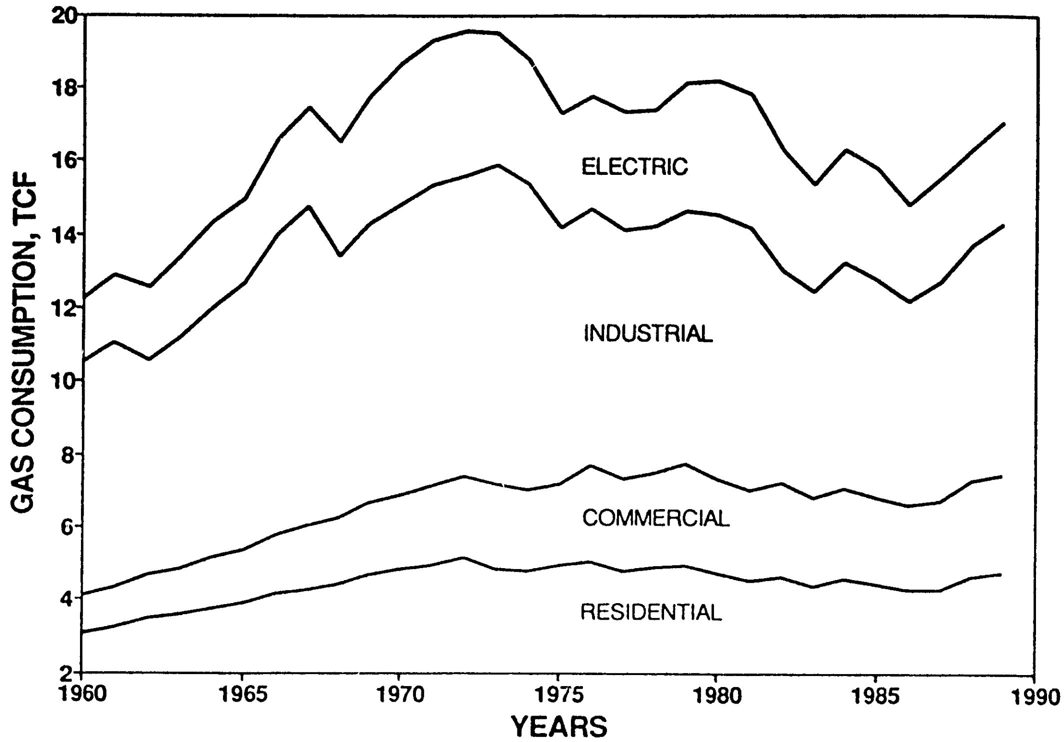

Figure 3. GAS CONSUMPTION BREAKDOWN -- 1960 TO 1989

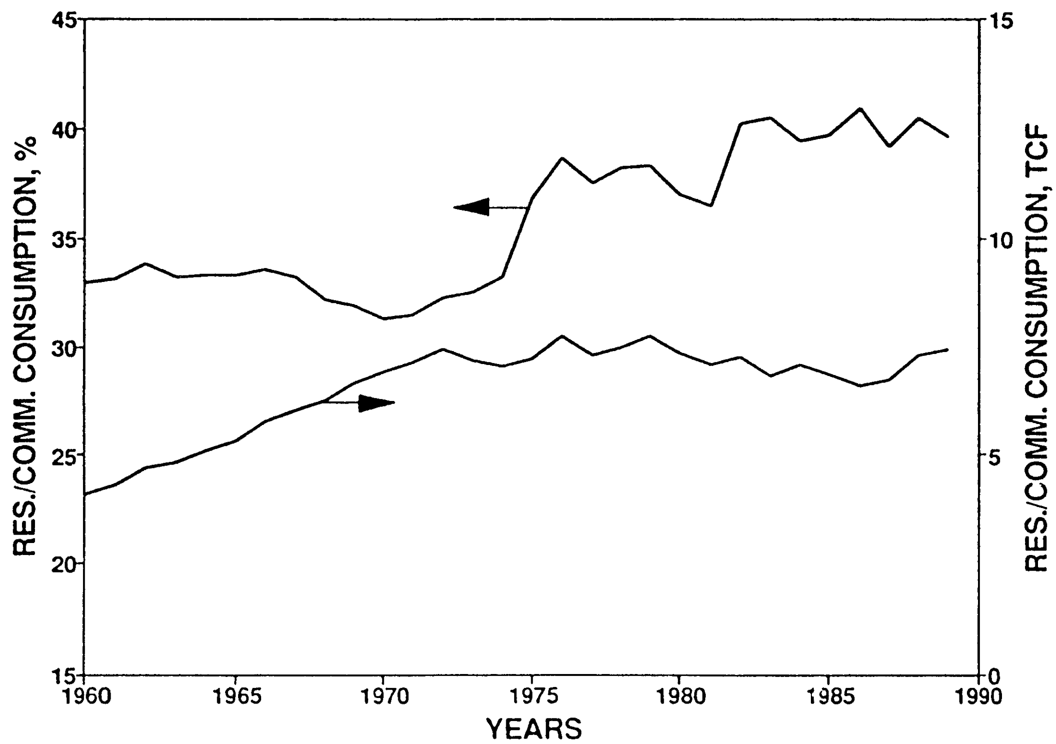

Figure 4. RESIDENTIAL/COMMER[illegible]AL GAS CONSUMPTION -- 1960 TO 1[illegible]9

- Total market expansion is anticipated [3]. Although the extent of this expansion will depend on many factors, storage capacity will be needed to provide additional deliverability in times of peak demand.

- Increasingly sophisticated gas consumers will require additional storage capacity as they take advantage of seasonal pricing and attempt to limit interruptible exposure.

- Changes in both supply and market areas will dictate the development of new local storage capacity.

Rationale for Inert Base Gas Use

Base gas must be purchased at the time a storage field is developed and is not normally cycled during field operation. When natural gas prices were substantially lower than they are today, the capital expenditure for base gas was a relatively minor fraction of total capital expenditures. For example, the purchase of 10 BCF of base gas (for a medium-sized storage field with a total inventory of just over 20 BCF) at a price of $.25/MCF would require $2.5 million of capital. Such prices for natural gas were not uncommon prior to the mid-1970's (Figure 1). At today's natural gas prices, the investment required to supply base gas is a major cost item for new storage fields. Base gas now represents one-third to one-half the investment cost in developing a new storage field. For example, the same 10 BCF of base gas at $1.50/MCF would require $15 million of capital.

The use of a less expensive inert gas as an alternative to natural gas for all or part of underground storage field base gas requirements could substantially reduce investment costs. Nitrogen is an example of an abundant inert gas that can be purchased at one-third to two-thirds of the price of natural gas. The price differential between nitrogen and natural gas provides a clear economic incentive for the use of nitrogen as an inert base gas in new underground storage fields. Existing storage fields contain base gas (natural gas) that has already been purchased and partially depreciated. Depending on the circumstances discussed below, some of these existing storage fields will also make good candidates for inert gas use by replacing existing natural gas with nitrogen.

The following discussion provides information on the technical aspects of inert base gas use and examines the economic and regulatory issues.

INERT BASE GAS TECHNOLOGY

The objective of using less expensive inert gas as base gas in underground storage fields to reduce costs must be accomplished without affecting the availability of pipeline-quality working gas from the storage field. When two miscible gases come into contact with one another, some mixing is unavoidable. Early studies [4,5,6] identified possible mixing between inert and natural gases as the key technical issue with respect to inert base gas use. Fortunately, the structure and network of interconnected pores that are a storage reservoir severely restrict the mixing process. Also, a strategy exists whereby mixing can be predicted and controlled. That strategy is based on the injection of inert gas on the flanks of a storage field (as opposed to injecting inert gas evenly throughout the field), where it will stay and perform the pressure and volume maintenance function of base gas without contaminating the working gas. Evidence that this strategy can be effective comes from both France and the United States.

French Experience

The French natural gas utility, Gaz de France (GdF), has experience with the storage of both natural gas and non-pipeline-quality gases in four reservoirs [7,8]. GdF's initial experience was at its Beynes storage field, which serves the Paris market. Until the early 1970's, GdF supplied Paris with manufactured gas (hydrogen and carbon monoxide). Starting in 1972, the Beynes reservoir was converted to a natural gas storage field. This was accomplished by injecting pipeline-quality gas into one side of the reservoir and simultaneously withdrawing manufactured gas from wells on the other side of the reservoir. By such a process, the main part of the storage field was swept free of manufactured gas, which was replaced with natural gas. At the end of this conversion, all of the working gas volume and 40% of the base gas volume of manufactured gas had been replaced with natural gas. However, manufactured gas still resided around the flanks of the structure in a volume equal to 60% of the base gas requirement for that storage field. Beynes has been operating as a natural gas storage field since the mid-1970's with no contamination of the natural gas working volume by the residual manufactured gas, which serves strictly as base gas.

The successful use of manufactured gas as base gas at Beynes led GdF to plan and implement inert base gas projects at three other storage fields to date: Saint-Clair-sur-Epte, Germigny-sous-Coulombs, and Saint-Illier. In all three cases, a nitrogen-based inert gas is used to supply 20% of the total base gas requirement. At St. Clair, combustion products were used as inert gas. At Germigny, a combination of combustion products and low-Btu gas was used. At St. Illier, nitrogen from an air separation plant is being injected. St. Clair and Germigny were new fields, with inert gas injection accomplished as part of the original development of those fields. St. Illier is an older field that had been fully developed prior to inert base gas use.

St. Clair is a good example of inert base gas use. Table 1 provides a summary of storage data for this field. Figure 5 is a structure map that shows the depth (in meters relative to sea level) to the top of the storage structure. In 1979 and 1980, as St. Clair was developed, 2.1 BCF of inert gas (20% of the base gas requirement) was injected. Well No. 7, shown in Figure 5, was used to inject the inert gas. Figure 6 shows the position of inert gas near the end of the development of the field in 1981. As shown in the shaded area in Figure 6, the inert gas is confined to the structurally low flanks of the field (mainly to the south), away from the main injection/withdrawal area in the center. No contamination of working gas by inert gas has been experienced during the normal operation of St. Clair since its development. GdF's experience with inert base gas to-date has been so successful that the utility intends to inject inert base gas in all of its storage fields (11 aquifers).

United States Experience

In the fall of 1986, the Gas Research Institute (GRI) initiated a research effort at the Institute of Gas Technology (IGT) in coordination with IGT's Sustaining Membership Program (SMP) to develop a systematic approach that can be applied by the U.S. gas industry to implement the use of inert base gas in its storage fields. GdF, through its subsidiary Sofregaz, was included as a major subcontractor in this effort.

The systematic approach defined involves the following four steps [9]:

1. The selection of a storage field with favorable geological characteristics that will allow careful placement of inert gas so that it will remain isolated from normal injection/withdrawal operations.

2. The collection and analysis of data to define the reservoir, fluid properties, and pressure/production behavior over time.

3. The engineering analysis (utilizing a reservoir simulator) to evaluate viable options for proper placement of inert gas in the reservoir such that in the long-term, pipeline-quality gas delivery is assured.

4. The preparation of a field implementation plan based on the results of the engineering analysis performed.

To demonstrate the utility of such a systematic approach, three companies (Columbia Gas Transmission Corporation, Northern Illinois Gas Company, and Texas Gas Transmission Corporation agreed to participate in the development of an illustrative example.

The three participating companies operate a total of 61 storage fields. Site selection criteria were used to choose Hanson storage field, operated by Texas Gas Transmission Corporation, as the illustrative example for further analysis. Table 2 is a summary of storage data for Hanson field. Figure 7 is a structure map on top of the storage zone at Hanson. The shaded area shows the inert gas injection target zone on the western flank of the field. An analysis based on the four-step systematic approach indicated that 400 MMCF of inert gas (nitrogen) could be placed in the target zone at an injection rate of 2 MMCF/day. Long-term model runs indicated that this inert gas injection strategy would not result in the production of measurable nitrogen in withdrawn natural gas.

Table 1. SUMMARY OF STORAGE DATA:
SAINT-CLAIR-SUR-EPTE STORAGE FIELD, GAZ DE FRANCE

Beginning of Operation	1979
Storage Type	Aquifer
Storage Formation	Bioclastic and Oolithic Limestone
Depth, ft	2435
No. of I/W Wells	11
No. of Observation Wells	17
Thickness of Storage Zone, ft	105
Total Porosity, %	21
Permeability, md	700
BHP of Untapped Aquifer, psi	1200
Total Storage Capacity, $10^9 ft^3$	21
Working Gas, $10^9 ft^3$	10
Cushion Gas, $10^9 ft^3$	
Natural Gas, $10^9 ft^3$	8.9
Inert Gas, $10^9 ft^3$	2.1
Maximum Withdrawal, $10^6 ft^3/d$	140

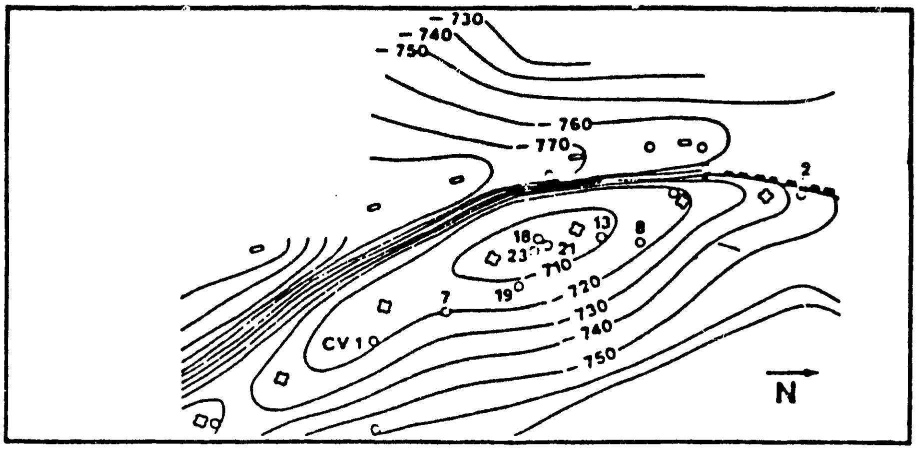

Figure 5. STRUCTURE CONTOUR MAP ON TOP OF GAS STORAGE RESERVOIR, SAINT-CLAIR-SUR-EPTE FIELD, GAZ DE FRANCE

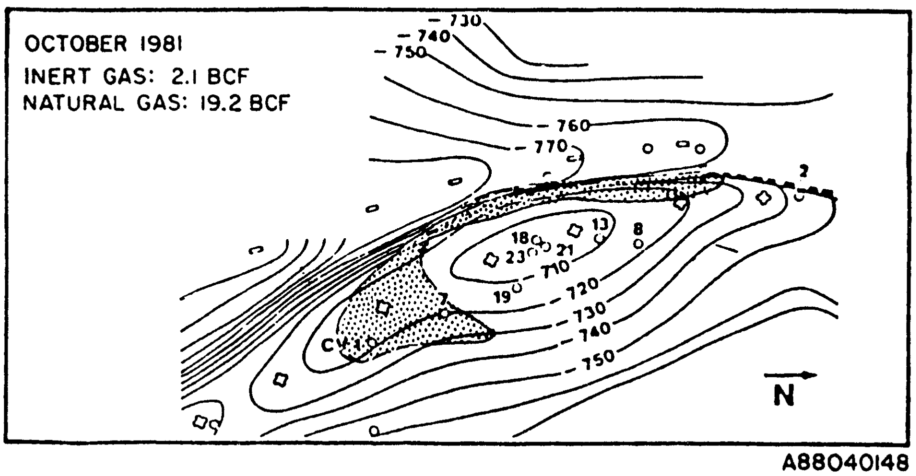

Figure 6. INERT GAS LOCATION IN SAINT-CLAIR-SUR-EPTE STORAGE FIELD IN OCTOBER 1981

At the conclusion of this analytical study, IGT was approached by Citizens Gas and Coke Utility, who offered its Simpson Chapel storage field as a candidate for a full-scale field test of inert base gas use. A detailed study of this storage field -- again using the four-step systematic approach -- revealed that Simpson Chapel is not a good candidate for inert base gas use. Specifically, Simpson Chapel has an extensive natural fracture system that would result in an unacceptable amount of mixing. At present, we are searching for other candidate storage fields to serve as the first field test of this technology in the U.S.

ECONOMIC AND REGULATORY ISSUES

The economics of inert base gas use in underground storage fields will depend on many factors, including the quantity of natural gas to be replaced with inert gas, the costs of inert gas, the current price and book values of displaced base gas, the cost of inert/methane separation, if required, and the cost of the development of a plan for inert gas injection. As these factors are unique for each potential application, the economics of inert gas injection must be worked out on an individual storage field basis. However, the general issues involved in economic and regulatory considerations are summarized below.

The economic incentives for inert base gas use in underground storage fields are different for new and existing storage fields. For new storage fields, most base gas must be purchased at prevailing prices and the economic incentives are relatively straightforward. Less expensive inert gas can be substituted for natural gas as the field is being developed. The price differential between inert and natural gases then would amount to lower capital expenditures for the new storage development project. In addition, treatment of both the unrecoverable natural base gas and all inert base gas as capital expenditures may enhance economic benefits due to increased depreciation.

The use of an inert base gas in existing storage fields will cause the displaced natural gas to become working gas. The displaced natural gas reduces the volume of normal gas supplies that the operator must purchase (on a one-time basis) to fill the storage field. The operator, therefore, will have lower operating costs resulting from the price differential between the inert gas injected and the natural gas that would otherwise have been purchased to fill the storage field. In addition, the value of (displaced) working gas available to consumers will be determined by the accounting system employed by the operator. In the Last-In/ First-Out (LIFO) system used by most companies, the displaced natural gas will reflect its acquisition cost and may present significant savings for consumers.

An investigation of regulatory consequences of inert base gas use [9] indicated that approval by the Federal Energy Regulatory Commission (FERC) for such projects can be obtained under Section 7 of the Natural Gas Act. Intrastate companies may not be required to seek such authorization but probably should to assure that the costs of inert base gas substitution can be recovered.

Table 2. SUMMARY OF STORAGE DATA:
HANSON STORAGE FIELD

Beginning of Operation	1965
Storage Type	Depleted Gas Field
Storage Formation	Tar Springs Sandstone
Depth, ft	2250
Number of Injection/ Withdrawal Wells	31
Number of Observation Wells	3
Net Pay, ft	24
Total Porosity, %	17
Permeability, md	95
BHP of Untapped Aquifer, psia	1061
Total Storage Capacity, 10^9 ft^3	12
Working Gas, 10^9 ft^3	4
Base Gas, 10^9 ft^3	8
Design Deliverability, 10^6 ft^3/day	71

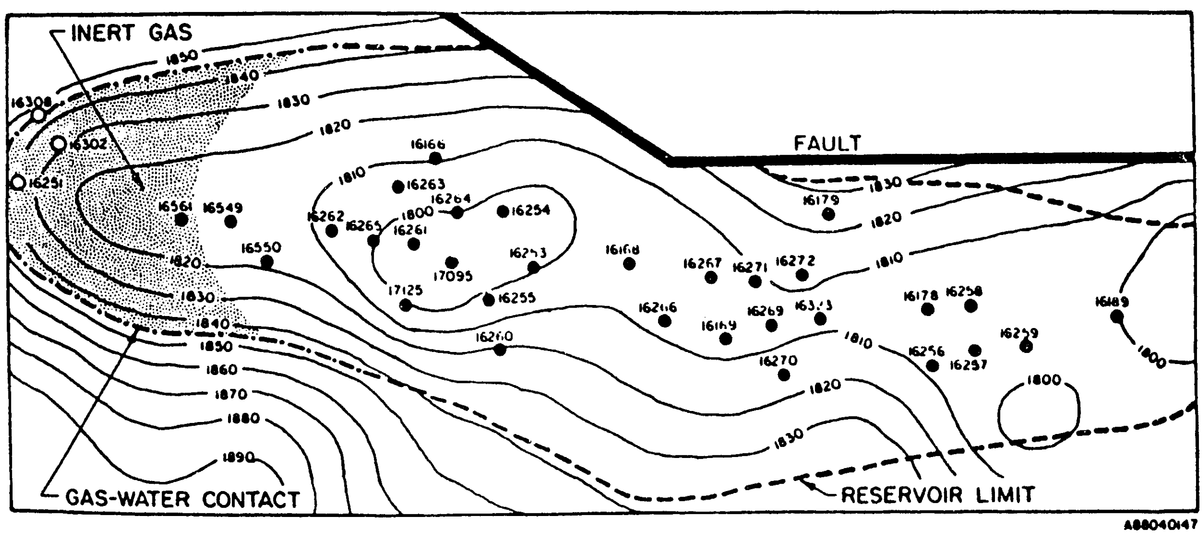

Figure 7. STRUCTURE CONTOUR AND WELL LOCATION
MAP OF HANSON STORAGE FIELD

If inert base gas use is implemented for an existing storage field, FERC and state regulatory officials may argue that base gas that is replaced by inert gas could be sold only at the acquisition price. The conventional procedure for pipeline companies would be to credit excess revenues for the sale of base gas to the purchased gas adjustment (PGA) account, which would result in all economic benefits accruing to the consumer. Where a PGA is not applicable, the lower cost gas could replace field purchases so that, in effect, the difference between acquisition cost and sales price would accrue to the company. Other schemes to split economic benefits between customers and company are possible but would have to be tested.

The injection of an inert gas like nitrogen into a storage field should not cause any environmental problems. Storage wells are currently exempted from the provisions of the EPA's Underground Injection Control Program (under the Safe Drinking Water Act). It is likely that nitrogen injection in storage fields would also be exempted.

CONCLUSIONS

The use of inert gas (nitrogen, for example) as all or a part of the base (cushion) gas required to support underground natural gas storage operations is a promising technology that can reduce storage costs and conserve valuable natural gas supplies for consumers. Procedures have been developed that can be used by industry personnel to confidently plan and implement inert base gas projects. The technology is being successfully used in France, and a field test in the United States is being actively pursued.

New storage fields developed will require the acquisition of large volumes of base gas. The use of less expensive inert gas can result in considerable savings.

From a strictly technical perspective, the replacement of natural gas with inert gas for base gas in existing storage fields can be planned and accomplished. Accounting procedures and regulatory considerations will, however, preclude the application of inert base gas technology in some existing storage fields. New storage fields provide the most economically attractive targets for inert base gas use.

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