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ECONOMIC VIABILITY OF UNDERGROUND GAS STORAGE IN DEPLETED OIL RESERVOIRS IN NIGERIA

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Abstract

The economic viability of underground natural gas storage in depleted oil reservoirs was examined with reservoirs Z-16T and Z-16RS located onshore, South-East, Nigeria. The geologic and engineering information on the reservoirs were gathered with which the costs analyses were conducted. The storage costs and storage capacities of the reservoirs were used for profitability analyses through the expected revenues. It was shown that reservoir Z-16T has advantage over reservoir Z-16RS and is preferred for use as underground gas storage vessel having higher Internal Rate of Return (IRR) of 26.8% compared to 10.5% for reservoir Z-16RS and shorter pay-out period of 3.19 years and break-even point of $59.1 million as against 5.25 years and break-even point of $46.7 million for reservoir Z-16RS.

Key words: economics, storage; costs, revenue; profitability; analyses; investment; costs; NPV; break-even point; payout, IRR.

1. Introduction

Natural gas, a colourless, odourless gaseous hydrocarbon. Natural gas, like most other commodities, can be stored for an indefinite period of time [6].

The exploration, production, and transportation of natural gas takes time, and the natural gas that reaches its destination is not always needed right away, so it is injected into underground storage facilities. These storage facilities can be located near market centers that do not have a ready supply of locally produced natural gas. Underground storage is generally much more cost effective than aboveground storage for larger product capacities, both in investment costs and operating costs.

Evaluating the economic viability of underground gas storage is to determine the profitability of injecting gas into depleted oil reservoirs for storage purposes. Since the dream of any investor is to make profit, the target objective becomes injecting and withdrawing a considerable amount of natural gas to combat or stop flaring at the lowest possible overall costs. The gas produced and injected into the storage reservoir if continued to be flared would pose a very big loss of income, both the sales value of the gas and the flare penalty.

It involves the estimation of storage costs and the revenue realizable from the project at present and overtime. A number of operations are involved in the conversion of a depleted reservoir to an underground gas storage reservoir. These operations include the development of the storage facility and installation of the gas gathering systems. Developing the storage facility involves drilling and completing wells to be used for storage, observation and structural control.

The costs of carrying out these operations and many other are termed the initial investment costs and the annual storage costs are the costs of operating and maintaining the facility per year.

The revenue is the amount of money gotten from selling the working gas each year. The economic viability of underground gas storage in depleted reservoirs is analyzed by comparing and relating the costs and the revenue realizable from the project.

2. Procedure

To understand the fundamentals of natural gas storage, and the underlying motivations of the storage owners, it is often asked "how much does it cost to store gas". The energy marketers lease storage capacity both to increase the flexibility of product offerings to its customers and enhance profitability.

The economic flow chart for underground gas storage in depleted oil reservoir consists of the various costs at different stages: acquisition cost, development cost, cost of gathering facilities and cost of cushion gas, which are summed up to get the total cost of investment which will be added to the annual storage cost to get the total storage cost as shown in Fig 1 below.

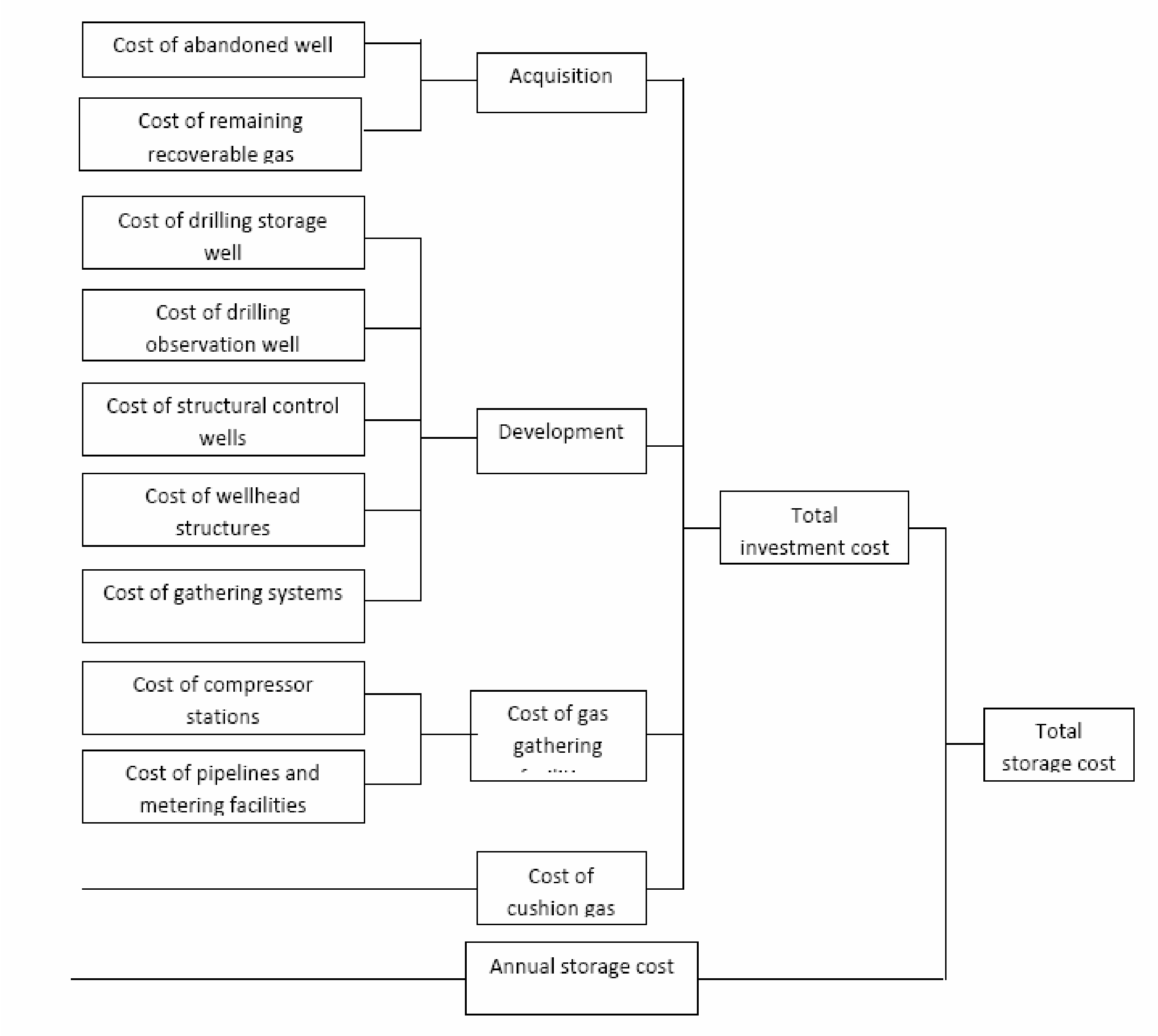

Fig 1 Economic flow chart for natural gas storage in depleted reservoir

2.1 Estimation of Storage Capacity (Inventory Verification)

The storage cost depends on the storage capacity of the reservoir which is used in the computation of the storage economics.

The storage capacity which represents the volume of gas required to replace the produced oil from the reservoir is given by Anyadiegwu[2] , as:

$$V = 5.615N_p[B_o/B_{gi} + (R_p-R_s)] \tag{1}$$

Volume of gas required to replace the entire producible oil in the reservoir ie the total storage capacity =

$$V = 5.615N[B_o/B_{gi} + (R_p-R_s)] \quad (2)$$

2.2 Costs Analysis

As with all infrastructural investments in the energy sector, developing storage facilities is capital intensive. Investors usually use the return on investment as a financial measure for the viability of such projects. It has been estimated that investors require a rate of return between 12 percent to 15 percent for regulated projects, and close to 20 percent for unregulated projects. The higher expected return from unregulated projects is due to the higher perceived market risk. In addition significant expenses are accumulated during the planning and location of potential storage sites to determine its suitability, which further increases the risk [1].

The capital expenditure to build the facility mostly depends on the physical characteristics of the reservoir. First of all, the development cost of a storage facility largely depends on the type of the storage field. As a general rule of thumb, salt caverns are the most expensive to develop on a billion cubic feet (Bcf) of working gas capacity basis. However one should keep in mind that because the gas in such facilities can be cycled repeatedly, on a deliverability basis, they may be less costly. The wide price range is because of some region difference which dictates the geological requirements.

According to American Gas Association [1], these factors include the amount of comprehensive horsepower required, the type of surface and the quality of the geologic structure to name a few. A depleted reservoir costs between 800 million naira ($5million) to 1.12 billion naira ($7million) per Bscf of working gas capacity.

The conversion rate from naira to dollar as at May, 2012 is given as:

$$\$1 = N\ 160 \quad (3)$$

Finally, another major cost incurred when building new storage facilities is that of base gas. The amount of base gas in a reservoir could be as high as 50% for depleted reservoirs making them unattractive to develop when gas prices are high. The expected cash flows from such projects depend on a number of factors. These include the services the facility provides as well as the regulatory regime under which it operates. Facilities that operate primarily to take advantage of commodity arbitrage opportunities are expected to have different cash flow benefits than the ones primarily used to ensure seasonal supply reliability. Rules set by regulators can on one hand restrict the profit made by storage facility owners and on the other hand guarantee profit depending on the market model.

Several items contribute to the total investment necessary to put an underground storage field into operation, as demonstrated in Fig 1 [9]. They include:

i. Cost of acquisition of the old well and/or reservoir, Acquisition cost involves the: cost of acquiring the abandoned well, cost of purchase of the remaining recoverable gas or oil in the formation, cost of acquiring the right to use the formation for storage.

ii. Cost of development of the storage facility, consisting of: cost of drilling storage wells, cost of drilling observation wells, cost of structural control wells, cost of wellhead structures, cost of gathering system.

iii. Cost of gas gathering system.

iv. Cost of base or cushion gas.

The total investment cost is given by the equation below:

Total investment cost = Acquisition cost + Development cost + Gas gathering cost + Cost of cushion gas (4)

It is represented mathematically as:

$$I = A + D + G + C \quad (4a)$$

The total storage cost = initial investment cost + annual storage cost (5)

This is represented mathematically as:

$$S = I + N = A + D + G + C + N \quad (5a)$$

The price of Natural Gas as at May, 2012 was \$4.06/MMBtu = \$4.06/1000scf [4].

A Microsoft Visual Basic Program was developed using eqns 1 - 21, and was used to perform the economic analysis of the storage reservoirs, considering the different costs ranging from the cost of drilling a well to cost of installation of surface facilities. The results of the economic analysis are presented in tables and figures in this work.

2.3 Acquisition cost, (A)

Acquisition cost is the cost of acquiring the abandoned oil/gas well from the oil/gas producing company. It is always negotiable between the gas storage system operator and the oil producing company that produced oil from the well. The agreement is always on a lease arrangement. Acquisition cost is the sum of the cost of abandoned well and cost of the remaining gas in formation. It is expressed mathematically as:

$$A = C_{Wa} + C_{Grem} \quad (6)$$

2.4 Cost of acquiring abandoned well, (C_{Wa})

This equals salvage value of 20% of initial well cost.

Initial cost of well = Drilling cost (\$/ft) * Depth (7)

Salvage value of remaining oil well =

20% of Initial cost of well (8)

2.5 Cost of purchase of remaining recoverable gas in formation, (C_{Grem})

C_{Grem} = Gas price * amt of remaining recoverable gas (9)

2.6 Development cost, (D)

The development cost is the cost of drilling new wells and related activities like installation of wellhead structures required for the reconditioning of the depleted reservoir for underground storage facility. Six new wells are to be drilled in the course of developing the storage facility. One storage well would be needed: for injection withdrawal.

Five observation wells are also necessary, observation wells permit the measurements to verify that injected gas is confined to the designated area and has not migrated away. They control gas bubble evolution from the storage wells and observe leakage if gas leaks from the storage reservoir.

The development cost consists: i. Drilling cost, (C_D), ii. Cost of installing wellhead structures, C_{ws}, and iii. Cost of installing gathering systems, C_{gs}. It is mathematically expressed as:

For developing one well, $D = C_D + C_{ws} + C_{gs}$ (10)

2.7 Gas Gathering System

Gathering systems are defined as the flowline network and process facilities that transport and control the flow of oil or gas from wells to a main storage facility, processing plant or shipping point.

A gathering system includes some or all of these put together: pumps, headers, separators, emulsion treaters, tanks, meters and regulators, compressors, dehydrators, valves, pipelines and other associated equipment [2].

The cost of gas gathering system in this text is the sum of the costs of compressor stations, pipelines and metering stations. It is represented mathematically as:

$$C_{ggs} = C_{comp} + C_{pipeline} + C_{meter} \quad (11)$$

2.7.1 Compressor station

A reciprocating compressor of 200 - 1000billion hp whose daily input and output is 50 MMscf/day is chosen.

2.7. 2 Pipelines and metering stations

Pipeline diameters of 12', 14' and 18' and length of about 40 miles are commonly used, and 4 metering stations are installed [5].

2.7.3 Cost of cushion gas

Cost of cushion gas is estimated using 50cent/MMscf of working gas volume [11].

Cost = 50cent/MMscf working storage gas * working gas volume (12)

3. Financial Analysis

Based on the Energy Information Administration (EIA) standards, 1031Btu of average heat content is equivalent to 1 ft^3 Average gas price = \$4.06/MMBtu

1031Btu = 1scf (13)

According to Zachmann and Neumann[12]:

Reservoir Storage Cost per MMBtu = \$0.48 (14)

Annual Operating cost = Labour costs + Maintenance costs + Management costs (15)

Annual storage cost = Annual reservoir storage cost + Annual Operating cost (16)

Total storage cost = total investment cost + annual storage cost (17)

Gross Revenue = \$4.06 * Working gas capacity, Bcf/1000scf (18)

Net revenue for subsequent years of operation = = Gross revenue – Annual Storage cost (19)

4. Results

According to Philips[7],

- Cost of drilling a well per foot = \$150
- Cost of wellhead structures = \$10 000
- Cost of gas gathering system = \$50 000

Cost of compressor station = \$9 600 000 [8].
Cost of pipeline and metering stations = \$10 400 000[5].
According Latvian Business Guide[3],

- Annual labour costs = \$4 800 000
- Annual maintenance costs = \$7 240 000
- Annual management cost = \$804 000

Case 1 Reservoir Z-16T

Table 1 Reservoir and Fluid Data for Reservoir Z-16T

Discovery pressure, P	3955 psig
Saturation pressure	3002 psig
Reservoir temperature, T	216^{o}f
Stock tank oil in place, N	1.244 MMstb
Cumulative oil produced, Np	0.5825 MMstb
Gas compressibility factor, Z	0.86
Initial oil formation volume factor	1.405
Specific gravity r	26^{o}API
Height (h)	80 ft
Porosity, Ø	0.25
Initial oil water saturation	20 %
Permeability, k	30 MD
Well depth	11 000 ft

The storage capacity is computed using eq 1 as:
$V = 5.615 * 0.5825 * 10^6$ [1.4054/0.004156 + [3200 – 847.24]]= 8.8 Bcf
The total storage capacity is computed using eq 2 as:
$V = 5.615 * 1.2444 * 10^6$ [1.4054/0.004156 + [3200 – 847.24]] = 18.80 Bscf
The storage economics for reservoir Z-16T is computed using Microsoft Visual Basic Program, the results are summarized in Table 7.

Table 2 Summary of the cash flows for reservoir Z-16T

YEAR	INV	REV	EXP	NCR	CUM. NCR	PV @ 5%	PV @ 10%
0	$59.1M	-	-	($59.1M)	($59.1M)	($59.1M)	($59.1M)
1	-	$35.7M	$17.15M	$18.55M	($40.55M)	$17.67M	$16.86M
2	-	$35.7M	$17.15M	$18.55M	($22.0M)	$16.82M	$15.33M
3	-	$35.7M	$17.15M	$18.55M	($3.45M)	$16.02M	$13.94M
4	-	$35.7M	$17.15M	$18.55M	$15.1M	$15.26M	$12.67M
5	-	$35.7M	$17.15M	$18.55M	$33.65M	$14.53M	$11.52M
6	-	$35.7M	$17.15M	$18.55M	$52.2M	$13.84M	$10.47M
7	-	$35.7M	$17.15M	$18.55M	$70.75M	$13.18M	$9.52M
8	-	$35.7M	$17.15M	$18.55M	$89.3M	$12.56M	$8.65M

Calculation of Net Present Value and Internal Rate of Return

Net Present Value, NPV is a measure of profitability of any project. The net present value (NPV) or net present worth (NPW) of a time series of cash flows, both incoming and outgoing, is defined as the sum of the present values (PVs) of the individual cash flows.NPV compares the value of a dollar today to the value of that same dollar in the future, taking inflation and returns into account. If the NPV of a prospective project is positive, it should be accepted. However, if NPV is negative, the project should be rejected because cash flows will also be negative [10].

NPV = PV at 1yr + PV at 2yrs + PV at 3yrs + PV at 4yrs + PV at 5yrs + PV at 6yrs + PV at 7yrs + PV at 8yrs - PV at 0yr (20)

From Table 2, the Net Present Value, NPV at an expected rate of return/discount rate of 10% which is the sum of all the Present Values in that column = $8.65M + $9.52M + $10.47M + $11.52M + $12.67M + $13.94M + $15.33M + $16.86M - $59.1M = $39.86M.

The internal rate of return (IRR) on investment for a project is the rate of return that makes the net present value of all cash flows from a particular investment equal to zero. The higher the IRR of a project, the more desirable it is to undertake the project. Table 3 is a table of the net present values for reservoir Z-16T at various discount rates, which was used in generating a plot of NPV against discount rate as shown in Fig 2 for the determination of the IRR which is 26.8%. This value is the discount rate at which the NPV equals zero.

Table 3 NPV at various discount rates, reservoir Z-16T

Discount Rate (%)	NPV ($)
5	60.79M
10	39.86M
15	24.14M
20	12.08M
25	2.65M
30	(4.85M)
35	(10.90M)

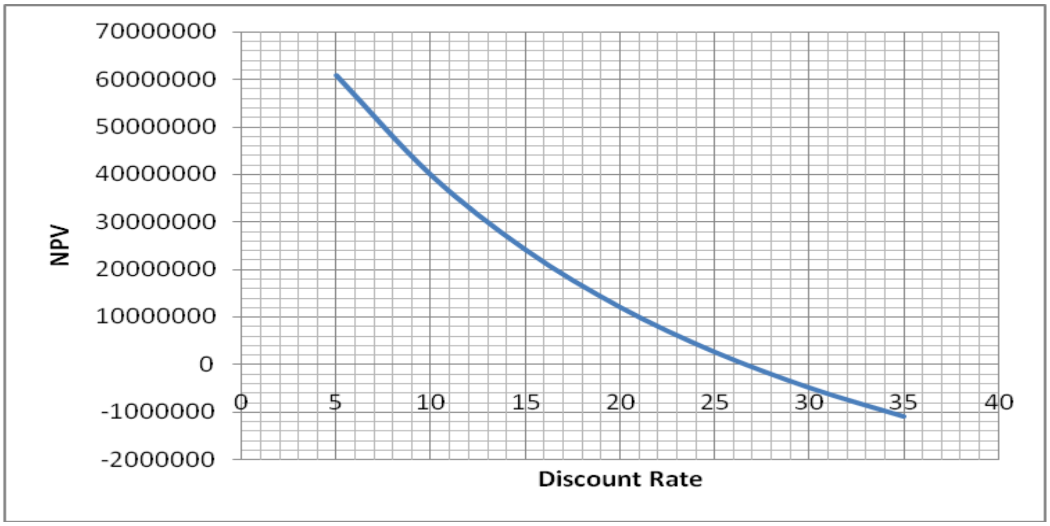

Fig. 2 Plot of NPV against Discount rate, reservoir Z-16T

Pay-out, PO, for Reservoir Z-16T

The pay-out for a project refers to the time (years) at which the initial investment on the project is just recovered. It is the time at which cumulative NCR becomes zero. From Table 4, cumulative NCR becomes zero between the 3rd and 4th year. In this project work, 3 and 4 years were used as the initial point (IP) and final point, (FP) respectively.
Applying interpolation:

$$(PO - IP) / (FP - IP) = (0 - \text{CUM NCR at IP}) / (\text{CUM NCR at FP} - \text{CUM NCR at IP}) \quad (21)$$

$$(PO - 3yrs) / (4yrs - 3yrs) = (0 - (- 3.45)) / (15.1 - (- 3.45))$$

Case 2 Reservoir Z-16RS

Table 4 Reservoir and Fluid Data for Reservoir Z-16RS

Discovery pressure, P	3000 psig
Reservoir temperature, T	200^{o}f
Stock tank oil initial in place, N	0.7714 MMstb
Cumulative oil produced, Np	0.3857 MMstb
Initial oil formation volume factor, Boi	1.319
Specific gravity, SG	0.9
Thickness, h	44 ft
Porosity, Ø	0.25
Initial oil water saturation	20 %
Density	8.141 lb/cu.ft
Well depth, D	9000 ft
Remaining gas in formation	4.43 Bscf
Oil API gravity	26^0 API

The working gas capacity is computed using eq 1 as:

$$V = 5.615 * 0.3857 * 10^6 [1.319/0.004851 + [3180 - 633.95]] = 6.1 \text{ Bcf}$$

The total storage capacity is computed using eq 2 as:

$$V = 5.615 * 0.7714 * 10^6 [1.319/0.004851 + [3180 - 633.95]] = 12.2 \text{ Bscf}$$

The storage economics for reservoir Z-16RS is computed using Microsoft Visual Basic Program as, the results are summarized in Table 5.

Table 5 Summary of the cash flows for reservoir Z-16RS

YEAR	INV	REV	EXP	NCR	CUM. NCR	PV @ 5%	PV @ 10%
0	$46.7M	-	-	($46.7M)	($46.7M)	($46.7M)	($46.7M)
1	-	$24.8M	$15.8M	$8.9 M	($37.8M)	$8.48M	$8.09M
2	-	$24.8M	$15.8M	$8.9 M	($28.9M)	$8.08M	$7.36M
3	-	$24.8M	$15.8M	$8.9 M	($20M)	$7.69M	$6.69M
4	-	$24.8M	$15.8M	$8.9 M	($11.1M)	$7.32M	$6.08M
5	-	$24.8M	$15.8M	$8.9 M	($2.2M)	$7.98M	$5.53M
6	-	$24.8M	$15.8M	$8.9 M	$6.7M	$6.64M	$5.03M
7	-	$24.8M	$15.8M	$8.9 M	$15.6M	$6.33M	$4.57M
8	-	$24.8M	$15.8M	$8.9 M	$24.5M	$6.03M	$4.15M

Calculation of Net Present Value

From table 5, the Net Present Value at an expected rate of return of 10% = $4.15M + $4.57M + $5.03M + $5.53M + $6.08M + $6.69M + $7.35M + $8.09M - $46.7M = $779 235

Table 6 is a table of the net present values for reservoir Z-16RS at various discount rates, which was used in generating a plot of NPV against discount rate as shown in Fig 3 for the determination of the IRR which is 10.5%. The curve crosses the discount rate axis at the point where discount rate is 10.5%.This 10.5% is the discount rate at which the NPV equals zero.

Table 6 NPV at various discount rates, reservoir Z-16RS

Discount Rate (%)	NPV ($)
5	10.76M
10	779 235
15	-6.83M
20	-12.62M

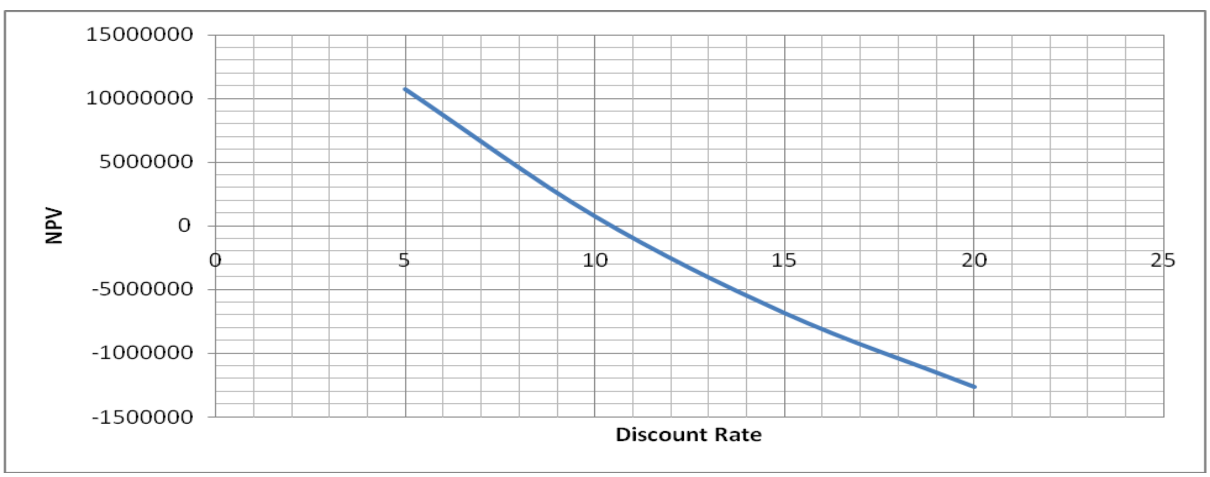

Fig. 3 Plot of NPV against Discount rate, reservoir Z-16RS

Calculation for Pay-out, PO:

Interpolating from the table,

(PO – 5yrs)/(6yrs – 5yrs) = (0 – (- 2.2))/(6.7 – (- 2.2))

PO = 5.25yrs

Table 7 Result of Storage Economics for Z-16T and Z-16RS

	Reservoir Z-16T	Reservoir Z-16RS
Total Storage Capacity	18.8 Bscf	12.2 Bscf
Working gas capacity	8.8 Bscf	6.1 Bscf
Acquisition cost	$28.79 million	$18.27 million
Development cost	$10.26 million	$8.46 million
Cost of gathering facilities	$20 million	$20 million
Cost of cushion gas	$4 400	$3 050
Annual storage cost	$17.15 million	$15.8 million
Total investment cost	$59.1 million	$46.7 million
Total storage cost	$76.25 million	$62.5 million
Gross Revenue	$35.7 million	$24.8 million
Annual Net Revenue	$18.55 million	$8.9 million
IRR	26.8%	10.5%
Cumulative NCR after 8 years	$89.3 million	$24.5 million
Pay-out	3.19 years	5.25 years
Break-even point	$59.1 million	$46.7 million
NPV @ 10% after 8 years	$39.86 million	$779 235

5. Conclusion

At the end of this work, it was found out that the economic viability of underground gas storage in depleted reservoirs could be determined.

Reservoir Z-16T was found to be more economically viable than reservoir Z-16RS since the former has higher IRR which is a major profit indicator.

Moreso, the NPV for reservoir Z-16T is higher than that of reservoir Z-16RS, and pay-out in years for reservoir Z-16T is less than that of reservoir Z-16RS as summarized in Table 7.

Finally, reservoir Z-16T is preferred to reservoir Z-16RS to be used for underground gas storage due to the economic analysis and profit indicators obtained for the two reservoirs as shown above.

Nomenclature

A	Acquisition cost
API	American Petroleum Institute
Bcf	Billion cubic foot
B_o	Oil formation volume factor
B_g	Gas formation volume factor
C	Cost of cushion gas
C_D	Drilling cost
C_{ws}	Cost of wellhead structure
C_{gs}	Cost of gathering system
C_{ggs}	Cost of gas gathering system
C_{comp}	Cost of compressor station
$C_{pipeline}$	Cost of pipelines
C_{meter}	Cost of metering station
CUM. NCR	Cumulative Net Cash Recovery
D	Development cost
EXP	Expenses
G	Gas gathering cost
I	Initial investment cost
INV	Investment
IRR	Internal Rate of Return
M	Million
MD	Millidarcy
MMSTB	Million stock tank barrel
MMscf	Million standard cubic foot
N	Annual storage cost

NCR	Net Cash Recovery
psia	Pounds per square inch (atmospheric)
psig	Pounds per square inch (gauge)
PV	Present Value
REV	Revenue
R_p	Gas oil ratio
R_s	Gas solubility
S	Total storage cost
scf	Standard cubic foot
^0F	Degree Fahrenheit
^0R	Degree Rankine

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