Liquid-Free Stimulations - CO_2\Sand Dry-Frac

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INTRODUCTION

A demonstration project to introduce a unique stimulation process that was previously unavailable to U.S. markets has been initiated. The process utilizes liquid carbon dioxide (CO_2) to both create hydraulic fractures and to transport proppants. Carbon dioxide is unique because it vaporizes at reservoir conditions and leaves only a liquid-free proppant pack.

The process requires a pressurized closed-system blender to mix the proppant with liquid CO_2. The process is non-damaging and can be beneficial to liquid-sensitive reservoirs that are damaged by conventional water-based hydraulic stimulation processes.

OBJECTIVES

- Identify liquid-sensitive reservoirs and operators to demonstrate and compare the production performance from wells stimulated with liquid carbon dioxide\sand (CO_2\sand) with that from conventionally stimulated wells, the purpose being to determine if CO_2\sand stimulations provide a superior result.

- Compare the net present value (NPV) of gas and oil wells stimulated with the non-damaging CO_2\sand treatment with those treated with water-based stimulations.

BACKGROUND

Many oil and gas bearing reservoirs benefit from hydraulic stimulation through increased production rates and thereby an improvement in the NPV. Actually, many wells would be non-commercial without the benefits of hydraulic fracturing. The process is routine in many reservoirs and an industry has developed to provide these services.

Hydraulic stimulations are achieved by pumping liquids at high pressure, and rates into the reservoir rock with sufficient energy to break or "hydraulically fracture" or "hydraulically stimulate" the formation to generate cracks or "fractures" through which gases and liquids can flow more rapidly to the well. This increase in production rate can significantly enhance the economics, without it many wells would be non-commercial.

In order to break the rock, the stimulation treatments often require energy both to overcome its tensile strength and also to overcome any additional tectonic forces which may be present. Both of these forces must be exceeded to generate a hydraulic fracture. Horsepower requirements of 2,000 to 5,000 are not uncommon to stimulate reservoirs and sometimes they are much larger.

In the majority of locations where petroleum reserves benefit from hydraulic fracturing, there are tectonic forces present that can close the fracture when the hydraulic pressure is removed at the end of the pumping operation. Proppants are frequently used to keep these fractures from closing completely.

There are several considerations regarding proppant selection relative to its strength and secondarily to its size. Sand, which has been carefully sized and cleaned, is the least expensive proppant and is generally selected when the more expensive, higher strength proppants are not required. The volume of proppant varies depending upon the fracture length and can range from 30,000 to 1,000,000 pounds. The history of proppants and their benefit is well documented.

The proppant is transported into the fractures by the pumped liquid, generally with enhanced properties to improve its fracturing and transport characteristics.

Water-Based Stimulations

Water-based fracturing liquids are the most commonly used. Generally, chemical additives are mixed with the water to improve its ability to transport the proppant. This is achieved through the addition of gels to increase the viscosity and also to reduce fluid loss from the fracture by temporarily plugging or bridging the natural permeability of the reservoir rock. Once the pumping is completed, by design these chemicals change; the gel by "breaking". The spent liquids can then flow from the reservoir and then the hydraulically created fracture can serve as a conduit for oil and gas to flow through the formation and to the well bore.

The use of hydraulic stimulations and chemicals to enhance oil and gas production has been very successful and many improvements have been realized since its inception in the 1950's. The gels sometimes do not completely break and there is always a residue following its decomposition. These materials, along with liquid blockage, damage the reservoir. Hydraulic stimulations that utilize gels create some damage but the fractures are of sufficient length to offset and overcome the damage, resulting in a net benefit.

PROBLEM

Some reservoirs, however, do not respond as effectively to hydraulic stimulations. Sometimes the nature of the reservoir is such that the fracturing liquids can become trapped because the reservoir is at a lower pressure and does not have sufficient energy to push the liquids back to the well bore. Some of these lower pressure formations are burdened by diminished economic potential because the liquids and chemicals used in the stimulation process remain in the reservoir and impede the flow of oil and gas.

Sometimes lengthy, and therefore costly, time periods are required to clean these stimulation liquids from the reservoir and in some instances the water is retained within the reservoir and the resulting damage becomes permanent.

SOLUTION

CO_2\Sand Stimulations

There is a process which can hydraulically stimulate petroleum reserves without creating the formation damage resulting from the gel residues and from the retained fracturing liquid. The use of CO_2 for hydraulic fracturing is unique because it can be pumped as a liquid and then it vaporizes to a gas and flows from the reservoir leaving no liquid or chemical damage (Figure 1). This process can also transport proppant in limited volumes but requires a specialized blender to mix the liquid CO_2 with proppant. The blender is a closed-system and unique (Figure 2). A blender is now licensed for U.S. operation by Universal Well Services.

There is now only one service company that can provide this service in the U.S. This process is generally unknown and has been resisted by other more well known pumping service companies.

Because no gelling materials or other chemicals are used the proppant transport capabilities and volumes are reduced. However, with the CO_2\sand dry-frac stimulation process, formation damage is eliminated, well clean-up is expeditious, and the economics significantly improved.

The process is best applied in tighter (less permeable), lower pressure, dry gas reservoirs where stimulation liquids are foreign to the formation and reduce its permeability to gas, and also in higher permeability reservoirs
where near well bore formation damage can be removed with this non-damaging process.

The initial cost is generally more expensive than conventional treatments but, when applied in liquid-sensitive reservoirs, can result in significantly improved economics through an increase in the NPV. The increase in the initial cost is because CO_2 is more expensive than the water and chemicals.

A higher initial stimulation cost, however, can result in a significant improvement in the economics through a faster payback and reduced well maintenance costs.

PROJECT DESCRIPTION

There have been several attempts to demonstrate this technology. Some, but not all, have been noticeably successful. Some reservoirs, because of their tight nature, which require long fracture extension, have not been as successful as liquid-sensitive reservoirs that are damaged by retained stimulation liquids.

In order to demonstrate these benefits, a fifteen (15) well study was conducted on a recognized liquid-sensitive reservoir to compare the production results of wells treated with two conventional stimulation types, nitrogen gas (N2) (no proppant) and also those treated with N2 foam stimulations. The specifics have been previously presented in SPE Paper #29191, "Analysis of Production Response to CO_2\Sand Fracturing: A Case Study," and in previous meetings to acquaint industry with the Department of Energy's (DOE) research and implementation efforts.

Carbon Dioxide (CO_2)

When Pumped	In Reservoir
Liquid	Gas
1. Creates fracture	1. Liquid free
2. Transports proppant	2. Sand propped fracture

Advantages

1. Liquid and residue-free propped fracture
2. Out performs other treatments in liquid sensitive reservoirs

Figure 1

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FRACMASTER

LIQUID CO_2 BLENDER

EQUIPMENT SERIES #9

Figure 2

RESULTS

The per-well results are that after thirty-nine (39) months:

GAS PRODUCTION COMPARISON

Stimulation Type	Production (MMcf per well)	Difference (MMcf per well)	Benefit
CO_2\Sand	83.7	---	---
N2 Gas	43.9	39.8	1.9
N2 Foam	19.7	64.0	4.2

TABLE 1

The cumulative production from this fifteen well study is attached (Figure 3).

It has been projected for five years, resulting in 110, 54, and 29 MMcf per well for the three treatment types, respectively (Figure 4).

The annual production from each type of completion was compared and the NPV for each treatment type calculated. It should be noted that all wells were treated with two stimulation stages, i.e., two stimulations per well. The NPV calculations included site preparation, material costs and water disposal (Table 2) but specifically not the other external factors, tubing, etc., which are presented later. A discount rate of 10% and unescalated monthly operating expenses of $300 were used for the projections:

NET PRESENT VALUE (M$)

Treatment Type	CO_2\Sand (Non-Liquid)	N2 Gas (Gas)(No Proppant)	N2 Foam (Liquid)
Treatment Cost	52.5	23.5	34.5
NPV ($2.00/Mcf)	55.4	25.7	-11.5
NPV ($3.00/Mcf)	111.0	53.3	2.6

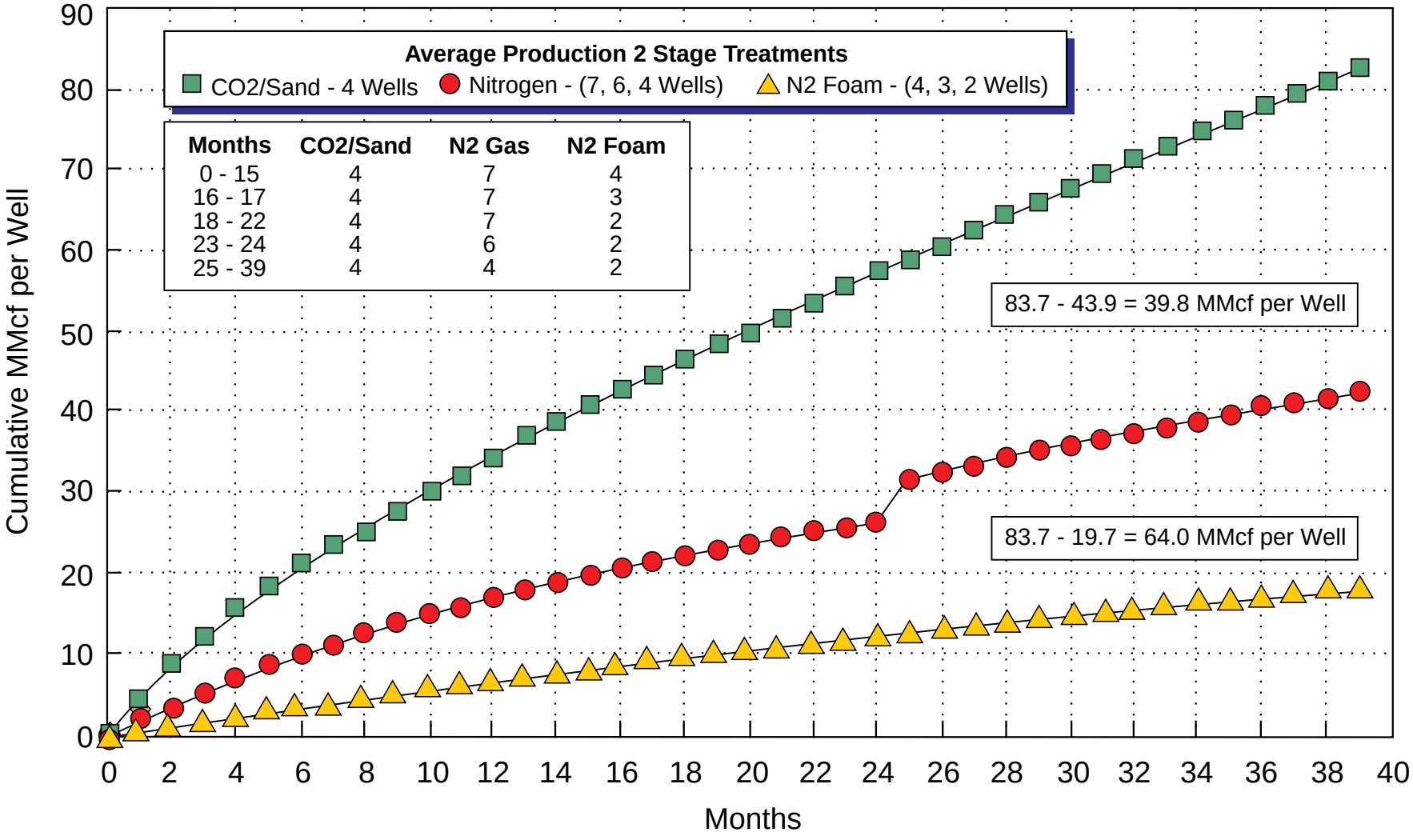
TABLE 3

These results indicated that the economics for the study group are most attractive for CO_2\sand and least for water-based stimulations, even for gas with a market price of $2.00 per Mcf (Figure 5 and Table 4).

If the price is increased to $3.00 per Mcf, then the benefits become very large (Figure 6).

Gas Production - Devonian Shale

Pike Co., KY - Groups 1 & 2



Months	CO2/Sand	N2 Gas	N2 Foam
0 - 15	4	7	4
16 - 17	4	7	3
18 - 22	4	7	2
23 - 24	4	6	2
25 - 39	4	4	2

Figure 3

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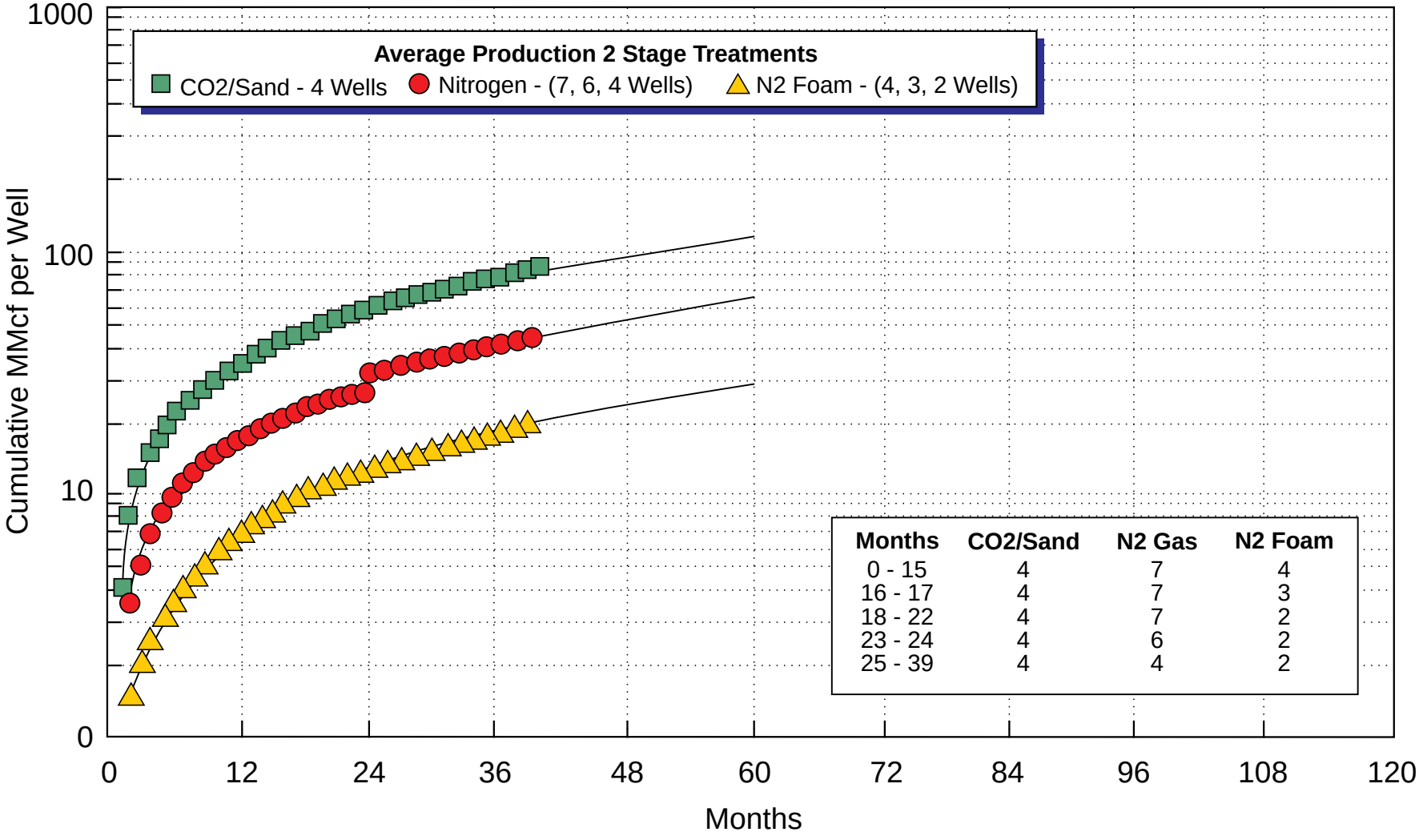
Gas Production - Devonian Shale

Pike Co., KY - Groups 1 & 2



Months	CO2/Sand	N2 Gas	N2 Foam
0 - 15	4	7	4
16 - 17	4	7	3
18 - 22	4	7	2
23 - 24	4	6	2
25 - 39	4	4	2

Figure 4

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NPV Input

Stimulation Type:	**CO2/Sand**		**N2 Gas**		**N2 Foam**	
Stage:	*1st*	*2nd*	*1st*	*2nd*	*1st*	*2nd*
Dozers (M$)	1.5		1.5		3.0	
Tanks + Water (M$)					1.5	1.5
CO2 (M$)	11.0	11.0				
N2 (M$)	1.2	1.0	12.0	10.0	7.0	6.5
Sand (M$)	2.4	2.4			6.0	6.0
Pumping (M$)	12.0	10.0			1.5	
Water Disposal (M$)					0.5	0.5
Close Pits (M$)						0.5
	28.1	24.4	13.5	10.0	19.5	15.0
Total 1st & 2nd Stages (M$)	*52.5*		*23.5*		*34.5*	

Table 2

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Net Present Value

$2.00/Mcf, OPEX=$250/mo., NRI=7/8, i=10%

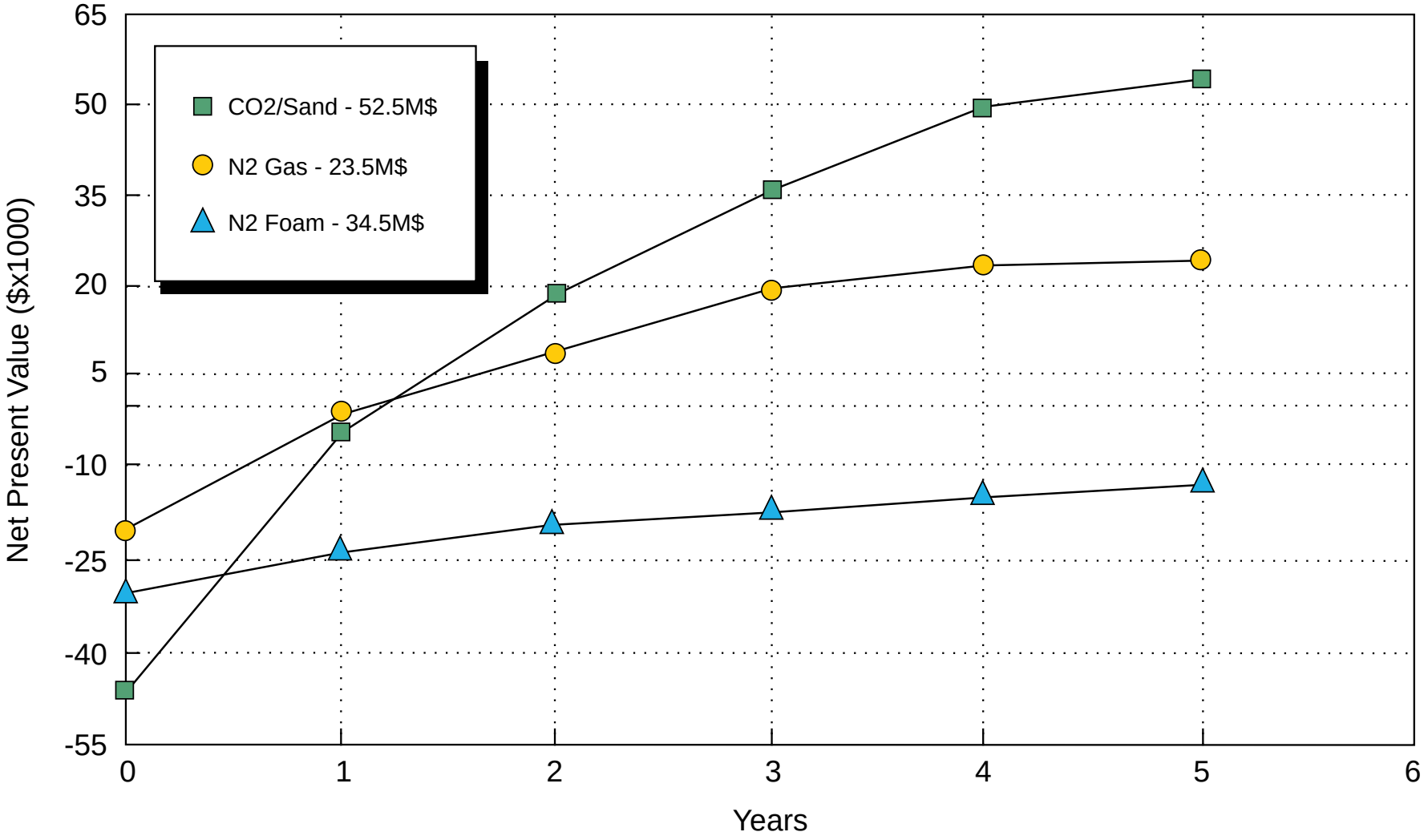

Figure 5

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Summary: 1st Five Producing Years

Devonian Shale - Pike Co., KY

Stimulation Type:	**CO2/Sand**	**N2 Gas**	**N2 Foam**
Proppant Volume (SXS/Stage):	450	0	1200
Stages:	2	2	2
Treatment Cost (M$):	52.5	23.5	34.6
Cum Production (MMcf):	110.0	54.0	29,0
Cum Cash Flow - 5 Year (M$):	125.0	56.0	1.1
Net Present Value i = 10% (M$):	55.4	25.7	-11.5

Table 4

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Net Present Value

$3.00/Mcf, OPEX=$250/mo., NRI=7/8, i=10%

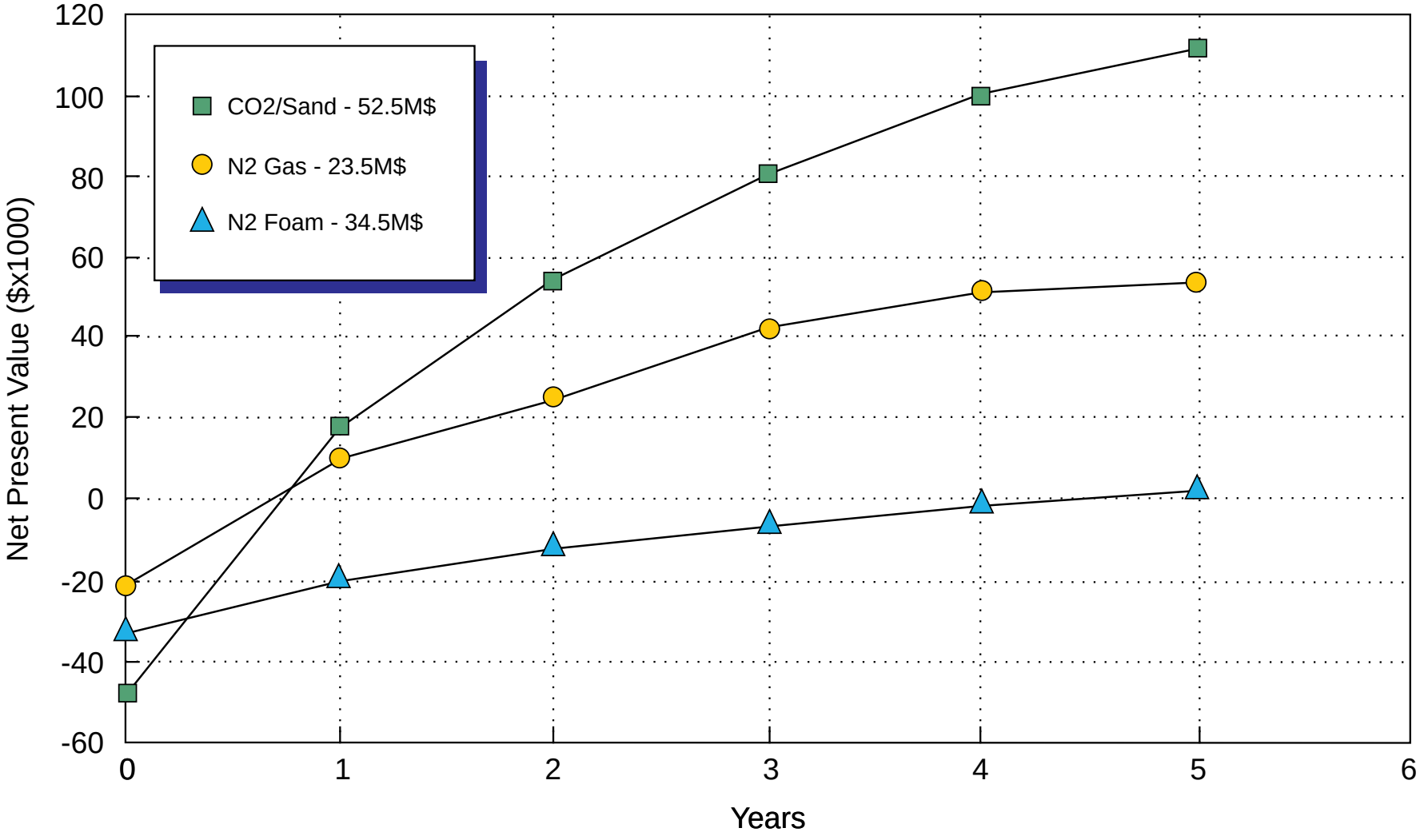

Figure 6

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External Factors

These results are significant but do not include the costs of the other stimulation related external factors. Because the costs of these external factors are site specific (Table 5), an additional 0.5 to 18.5 (M$) are associated with the stimulation costs for liquid-based stimulations - and will further depress the NPV's for liquid-type treatments.

Systems Analysis

An overall systems analysis of the true costs of water based treatments in liquid-sensitive reservoirs results in a significantly improved NPV when all of the external factors are considered.

The question for the test group of wells becomes, "should an operator be willing to spend an additional 29 M$ initially for an increase in NPV of 29.7 before external factors are considered?" If the CO_2\sand stimulations are compared with N2 foam treatments, then the improvement becomes 66.9 M$.

If the market price increases from $2.00 to $3.00 per Mcf then the increase in NPV becomes 57.7 M$ and 108.4 M$, respectively.

It should also be recognized that the test wells are 2-stage treatments and the differential benefits for single stage treatments is obviously more significant.

FUTURE ACTIVITIES

Candidate Well Identification

Emphasis is being directed towards developing a methodology to identify candidate well opportunities throughout the U.S. Previously, efforts had been focused on technical presentations, trade show exhibits, and developing an infrastructure within the oil and gas community. The results have been ineffective.

There is a great deal of resistance to this process because of a lack of familiarity with it and also market resistance from other, more well-known pumping service companies. In today's operating climate many oil and gas operators have alliances with the larger service companies who supply in-house engineering and pumping services at deep discounts. Because of these biases, it has been difficult to receive an objective assessment for a unique treatment that does not employ chemicals, gels, etc., and cannot be readily provided through the alliance.

A review of larger databases containing completion, stimulation, and production responses is being initiated. This effort will be directed toward identifying on-shore gas wells that have been producing since 1990. The wells will be identified as to producing formation, area, and operator. The stimulation type was not included in initial screening (Figure 7). Originally they were included but upon inspection it became apparent that, because of a peculiarity in the reporting, that some wells could be excluded. To avoid this eventuality it was decided to visually inspect

Systems Analysis

Stimulation Related External Factors

	Liquid	Foam	Gas	CO_2/Sand
Certain				
Water hauling & disposal	x	x		
Service Rig	x	x		
Cost ($M)	***2.0***	***0.5***	***0.0***	***0.0***
Probable				
Tubing	x	x		
Separator	x	x		
Tank	x	x		
Additional valves	x	x		
Swab rig	x	x		
Cost ($M)	***10.0***	***10.0***	***0.0***	***0.0***
Possible				
Pump & Rods - Installed	7.0	7.0		
Intermitter	1.0	1.0		
Cost ($M)	***8.0***	***8.0***	***0.0***	***0.0***

Table 5

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Screening CO2/Sand Target Formations

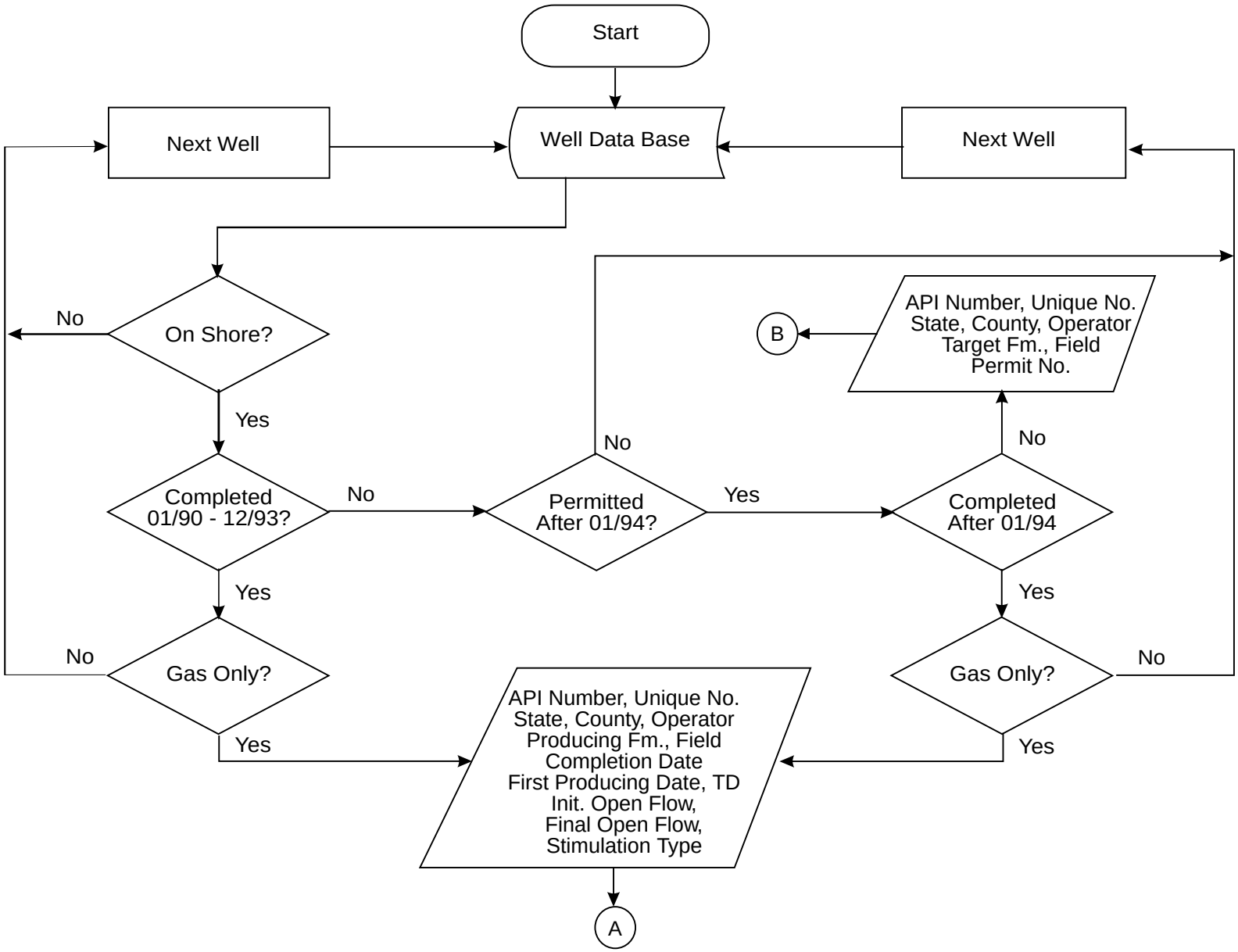

Figure 7

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and edit the data at this step. A frequency distribution analysis will then be generated to identify situations for which there are a sufficient number of wells and current drilling activity (Figure 8).

The resulting database will then be further reviewed to identify wells with negative decline curves, i.e., wells from which the production rate increases with time, indicating that the clean-up of stimulation liquids has resulted in a production increase. The output will provide a basis for identifying suitable candidate wells, reservoirs, and currently active operators.

CO_2 Transport

The viscosity of CO_2 is small, about one-tenth that of water, and much less than water with gels and other chemicals as typically used in conventional treatments.

Proppant transport relationships with liquid CO_2 have not been found in the literature. Additionally, because of the "thin" viscosity of liquid CO_2 and the absence of gels, it can readily "leak-off" from the fracture into the surrounding rock, thereby reducing its ability to transport proppant. In order to establish an understanding of this behavior and to develop stimulation models that consider these non-typical conditions, laboratory studies are being initiated. The present stimulation models do not address the unique behavior of liquid CO_2. Empirical relationships will be developed to describe the transport and leak-off of CO_2 into the surrounding rock in a controlled environment in a laboratory setting.

These will then be utilized to identify stimulation design sensitivities to maximum sand concentration and sand placement volume as a function of leak-off.

Demonstration Opportunities

Candidate well opportunities continue to be requested from operators to demonstrate this technology in suitable reservoir settings. A three well minimum is required in liquid-sensitive reservoirs.

Screening CO2/Sand Target Formations

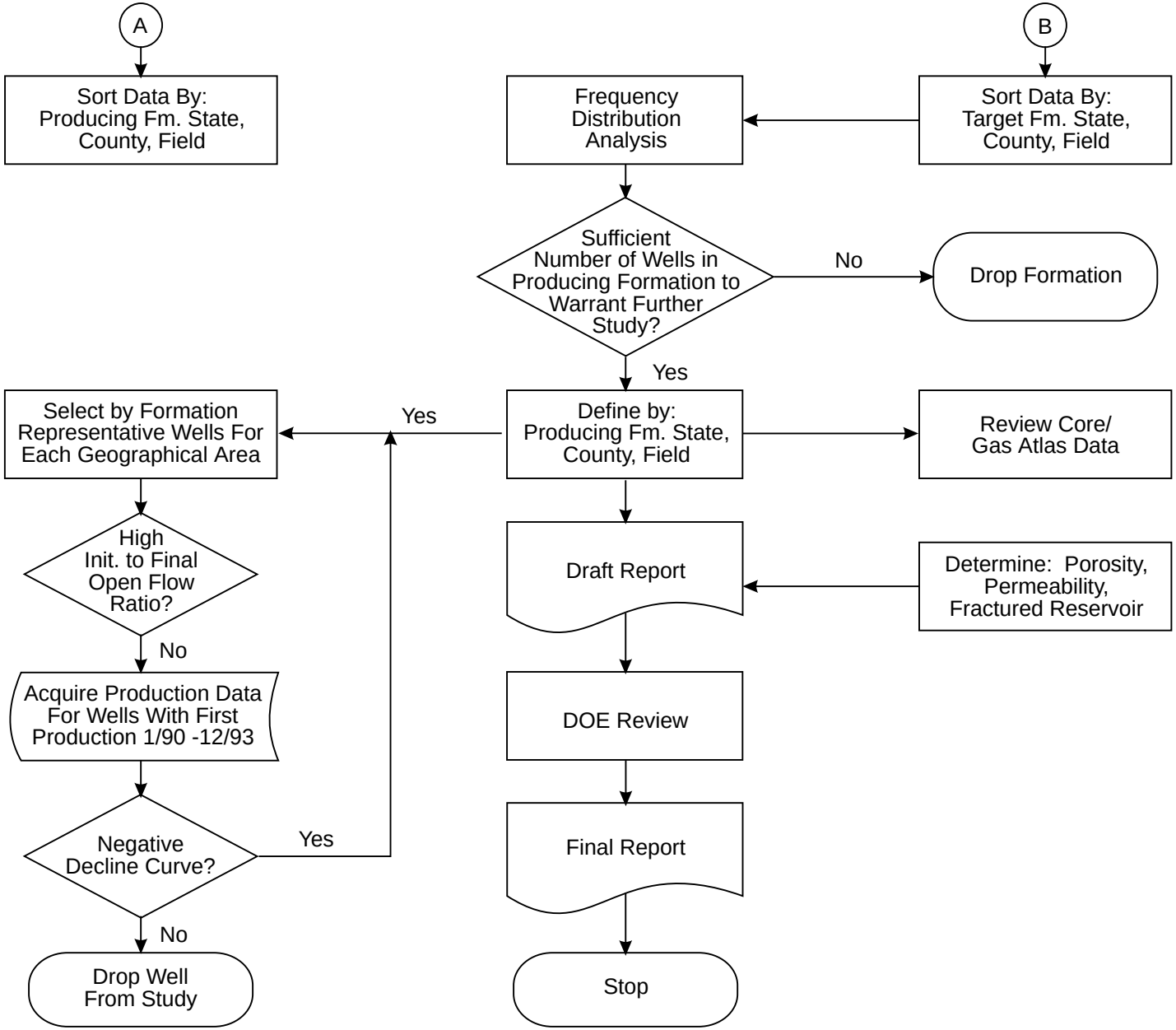

Figure 8

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