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Development of Local Nanomaterials for Treatment of Wells with High Water-Oil Ratio: An Experimental Approach

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Abstract

Nanotechnology involves the application of particles in the size range of 1 – 100 nm (Nanoparticles) in solving scientific and engineering problems. At this scale, materials show exceptional properties that makes them applicable in a wide range of areas. This work aims at identifying the kind of nanomaterials that will be suitable for treating wells with the problem of high water-oil ratio, developing them, and testing the effect of these nanomaterials experimentally in solving this problem. The methodology involves developing magnetic nanomaterials from which Nickel Ferrite ($NiFe_2O_4$) Nanomaterials was used as a case study, then through a core flooding experiment, a test was carried out and its effect on the water-oil ratio was noted.
After the experiment was carried out, semilog plots of WOR + 1 vs time, WOR vs Cumulative Oil and WOR + 1 vs Cumulative Oil were drawn and the water-oil ratio showed significant decrease with time and cumulative oil increased. In conclusion, from this study, we were able to determine that the application of Magnetic Nanomaterials can be useful in solving the problem of wells with high water-oil ratio.

1. Introduction

The present worldwide daily water production from oil wells averages roughly 3 BWPD per barrel of oil [1]. It costs money to lift water and then dispose of it. In a well producing oil with 80% water cut, the cost of handling water can multiply the normal lifting costs by two. Yet, wells with water cuts in excess of 90 % may still produce sufficient hydrocarbons to be economical. Water control technology is intended to reduce the costs of producing water. All oil fields under water drive, either from waterflood or a natural aquifer, eventually produce water along with oil [2]. This co-production of water is not peculiar to water driven reservoirs alone, as even reservoirs driven by gas-cap or depletion drive can produce some water [3]. The extra cost of handling water produced alongside oil and the problems associated with co-production of water makes it essential to control this problem. Nanotechnology, in engineering terms, is concerned with the fabrication and uses of devices so small that the convenient unit of measurement is the nanometer ($10^{-9}\ meter$) [4]. We can define nanotechnology, in engineering terms, as the "direct control of materials and devices on the molecular and atomic scale" [5]. The industry needs stunning discoveries in underlying core science and engineering. Breakthroughs in nanotechnology open up the possibility of moving beyond the current alternatives for energy supply by introducing technologies that are more efficient and environmentally friendly. Nanotechnology is characterized by collaboration among diverse disciplines, making it inherently innovative and more precise than other technologies. Such a technology may be the cornerstone of any future energy technology that offers the greatest potential for innovative solutions.

Generally, nanotechnology is the ability to create and manipulate matter at molecular level that makes it possible to create materials with improved (or, more accurately, altered) properties such being light weight and having ultrahigh strength, and greater capabilities such as in electrical and heat conductivity [7]. The production of water in oil well is almost unavoidable. The industry traditionally has lived with this problem by either separating and disposing of the produced water or by squeezing with a plugging agent to restrict water entry. The Introduction of strict governmental regulations to control the disposal of produced water has rapidly increased the cost of handling high water. For example, in one field, the cost to lift, separate, and dispose of the produced water is $.15 per barrel.

The use of magnetic nanoparticles such as Nickel Ferrite, magnetite and maghemite provides a more generalized solution to the problem of wells with high water-oil ratio [6].

2. Methodology

As the aim of this research is to develop local nanomaterials that can treat wells with the inherent problem of high water-oil ratio, and to test its effect in curbing this problem, an experimental approach is employed, before developing a numerical approach based on the vital parameters that form the basis of the experiment carried out.

Firstly, in developing the local nanomaterial, which in this case is Nickel Ferrite $(NiFe_2O_4)$ nanoparticle, a number of methods can be employed, but for the purpose of this work, the sol-gel method was used because of its high reaction rate, low preparation temperature and production of small particles. Then a core flooding experiment is carried out using the prepared Nickel Ferrite $(NiFe_2O_4)$ nanoparticle to test its effect on water-oil ratio. Core flooding experiments are the most effective means of testing the effect of nanomaterials on a general scale.

After this, a numerical basis for estimation based on the experiment carried out is developed with respect to important parameters that were varied during the experiment, such as flow rate, and concentration.

The process used in achieving the objectives are outlined below:

- Preparation of Nickel Ferrite $(NiFe_2O_4)$ nanoparticle.
- $Core\ Flooding\ Experiment$
- Numerical Estimation

2.1 Preparation of Nickel Ferrite $(\boldsymbol{NiFe_2O_4})$ nanoparticle

A ferrite is a type of ceramic compound composed of iron oxide $(\boldsymbol{Fe_2O_3})$ combined chemically with one or more additional metallic elements. The sol-gel method is widely used in synthesis of ferrite nanocrystals because of its high reaction rate, low preparation temperature, and production of small particles.

2.2 Materials Used:

The materials used include:

a) Nickel nitrate hexahydrated
b) Ferric nitrate hexahydrated

c) Citric acid
d) Polyvinylalcohol (PVA)

2.3 Procedure

Nickel Ferrite was prepared through Sol-gel auto combustion method. The gel was prepared stoichiometrically by dissolving an appropriate amount of metal nitrates and citric acid in a minimum amount of distilled water separately at 65^0C. The molar ratio of nitrates used was 2: 1 (Fe:Ni) and nitrates to citric acid 1:1. The resulting mixture was stirred for 1 hour and 1,2 ethane diol and NaOH was added to the reactions as a complexing agent and combustion process chemical additives (CPCA) respectively. The resulting solution was then stirred vigorously for 4 hours after which it was subjected to rapid evaporation at 110^0C. After concentration, the slurry turned from orange colour to a brownish transparent gel. The slurry was then oven dried for 48 hours at 80^0C. The oven-dried precursor was further grounded into powder in an agate mortar. It was preheated in the furnace at 600^0C for 1hr after which it was sintered in air at 750^0C. The precursor colour turned brownish-grey.

2.4 Core Flooding Experiment

2.4.1 Materials/ Equipment Needed:

- Core Flooding Experimental Setup
- Brine
- Nickel Ferrite ($NiFe_2O_4$) nanoparticle

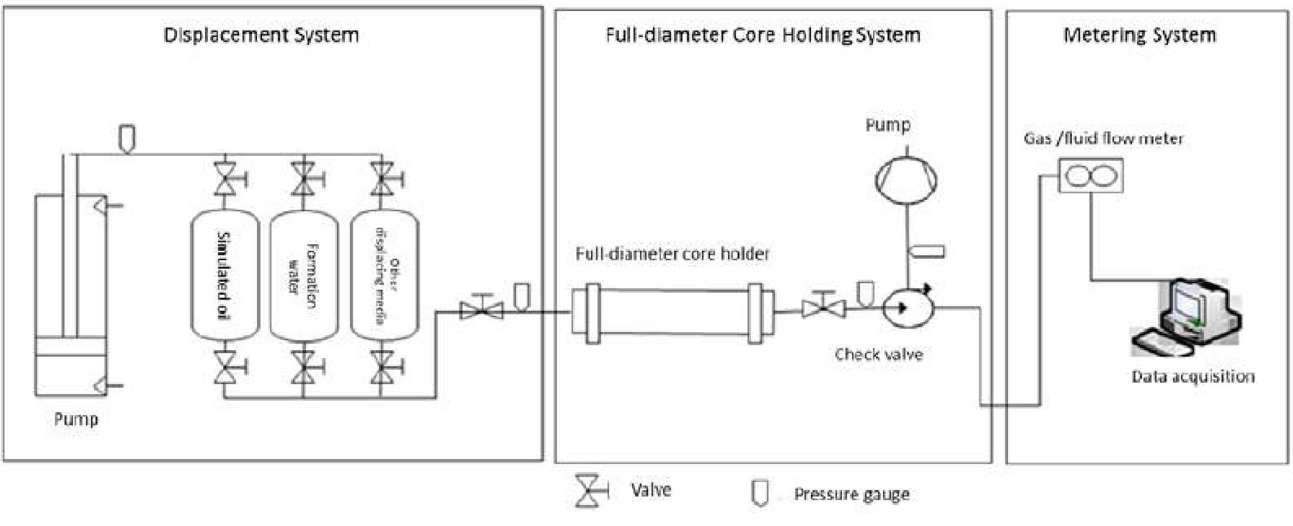

Figure 1. Schematic of a Core Flooding Experimental Setup

In the setup for the core flooding experiment, three distinct systems are prominent:

- Core Holding System
- Displacement System
- Metering System [7]

2.5. Experimental Procedure:

a) Wash all equipment and apparatus needed to run the experiment.
b) Check and note important information, which are necessary for the analysis of result, but may be altered during the course of the experiment, such as the water-oil ratio of the crude
c) Saturate the core with water.
d) Then pump in the crude oil to displace the water from the core.
e) Dissolve some amount of the Nickel Ferrite $(NiFe_2O_4)$ nanoparticle in brine, note the concentration and flow at varying flow rates (maybe five different flow rates) to displace the crude oil.
f) Then increase the concentration of the mixture of Nickel Ferrite $(NiFe_2O_4)$ nanoparticle and brine steadily and flow at the different flow rates for each concentration.
g) For each case measure the water-oil ratio.

After the experiment, we should be able to determine the effect of the Nickel Ferrite $(NiFe_2O_4)$ nanoparticle on the water-oil ratio based on concentration and flow rate, find suitable relationships and develop a numerical means of estimation. It should be noted that the gravity method was used in carrying out the experiment due to some limitations in getting the standard experimental setup.

3. **Result and Discussion**

The results obtained from the experiment carried out are displayed and analyzed and as shown in appendix 1.0. Composition of $(NiFe_2O_4)$ Nanoparticle.

Table 2.0: Table of values obtained at 0.05 g/cc concentration of Nickel Ferrite Nanoparticle

Time (k sec)	Water Volume (ml)	Oil Volume (ml)	Cumulative Oil (ml)	WOR	WOR + 1
0	0	0	0	0	0
0.24	4.6	0.2	0.2	23	24
0.28	4.6	0.6	0.8	7.666667	8.6666667
0.32	5.4	1.8	2.6	3	4
0.36	4.2	2.4	5	1.75	2.75
0.4	4	2.8	7.8	1.428571	2.4285714
0.46	4.2	3.4	11.2	1.235294	2.2352941
0.5	3.4	3.2	14.4	1.0625	2.0625

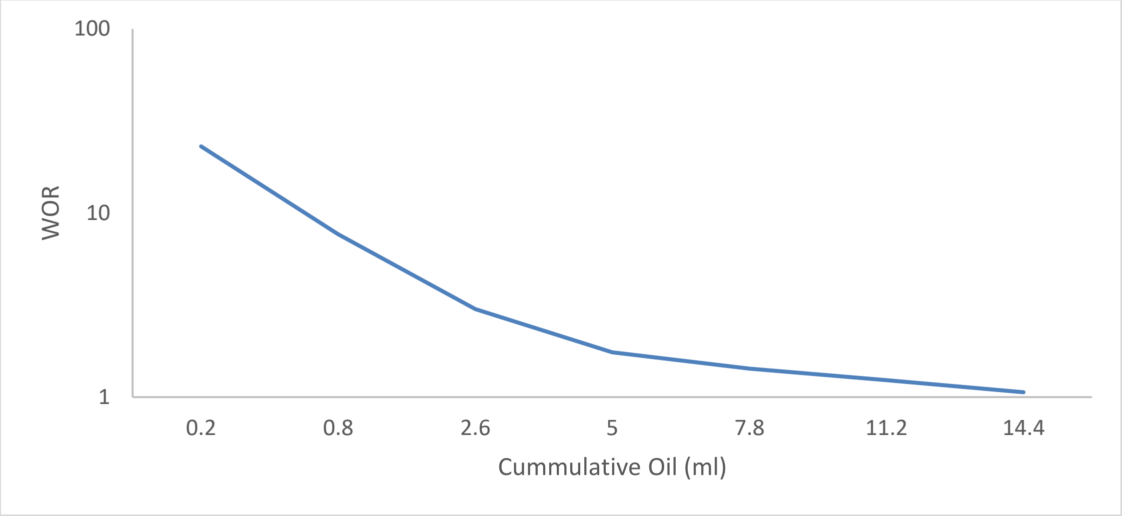

Figure 1.0. Semilog Graph of WOR vs Cumulative Oil at 0.05 g/cc Nickel Ferrite Nanoparticle Concentration

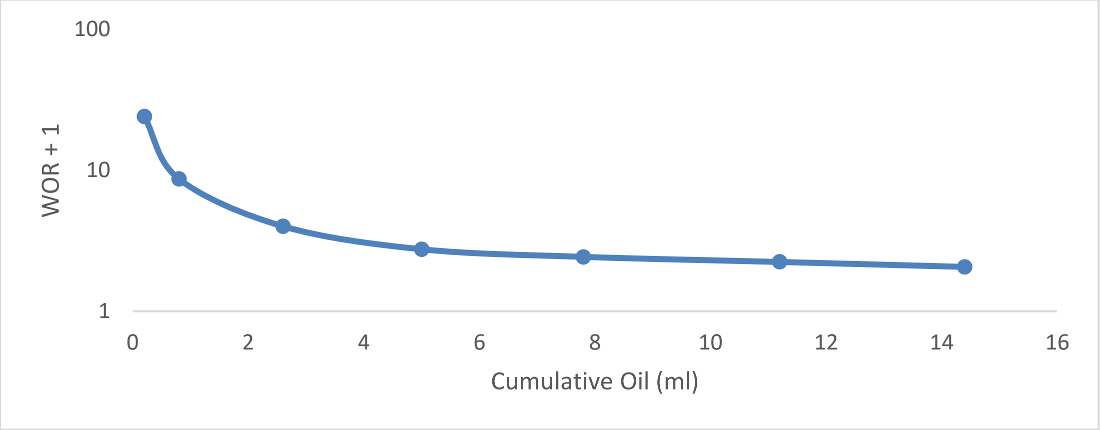

Figure 2.0. Semilog Graph of WOR + 1 vs Cumulative Oil at 0.05 g/cc Nickel Ferrite Nanoparticle Concentration

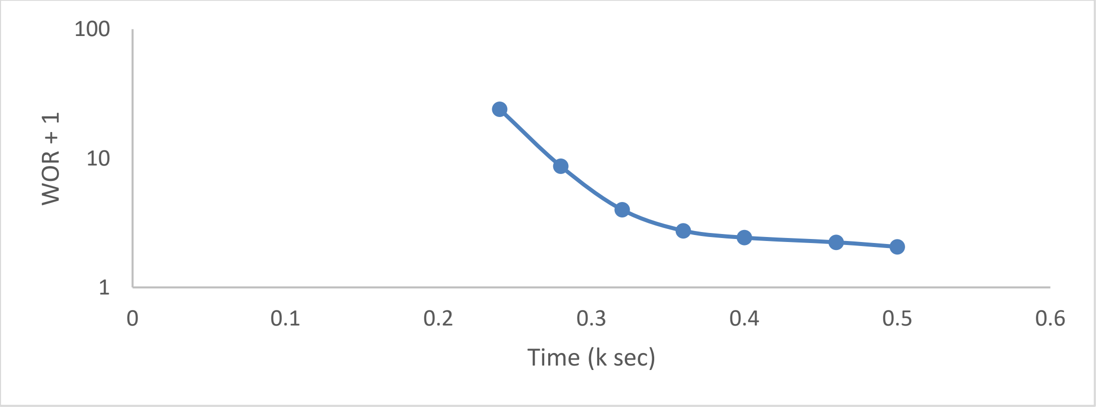

Figure 3.0: Semilog Graph of WOR + 1 vs Time at 0.05 g/cc Nickel Ferrite Nanoparticle Concentration.

a. Inferred Mechanism

From the experiment carried out, we are considering a situation where the reservoir is producing water at a rate beyond the economic limit either due to water coning, a strong natural water drive, or water breakthrough as a result of water flooding or water injection. The application of the nickel ferrite nanoparticle in solving this problem is expected to operate on the combination of mechanism based on wettability preference and mobility ratio.

b. Mechanism due to wettability

Noting that the nanoparticle is first mixed with brine before injection of the nanoparticle-brine mix, we can determine that with the injection of the nanoparticle, the reservoir regardless of its preferred wettability, starts to tend towards being more preferentially water wet. Due to this phenomenon, oil becomes more mobile, being displaced at a quicker rate, while water tends to be more static, adhering to the smaller pores of the rock as a result of the altered wettability preference. Hence, leading to an increase in oil produced, and a corresponding decrease in water-oil ratio.

*c.*Mechanism due to mobility ratio

This can also be explained in terms of mobility ratio in the sense that the mobility ratio which was greater than 1, hence favouring water mobility reduces to a value less than 1 as the nanoparticle was injected. The reduction in the mobility of water and a corresponding increase in the mobility of oil worked hand in hand in the reduction of the water-oil ratio. Therefore, Krw/Uw values reduced while the Kro/Uo values increased.

3.1 Assumptions made for plot's validity

a) Gravity and capillary forces are ignored, hence Buckley-Leverett equations is valid in its description
b) The percolation behavior is in agreement with Darcy's law
c) The temperature of the formation is constant

The dependence of the water-oil ratio on time or oil produced results from the interaction of two major effects:

1. The flowrate partition in streamtubes, due to the viscosity ratio, layering, flow pattern and heterogeneity and
2. The displacement in a given streamtube which is affected by the viscosity ratio and fractional flow.

3.2 Analysis of experimental results

Due to these two major effects, the experiment carried out worked on relating water-oil ratio with time and oil produced.

From Tables1.0 and 2.0 and Figure 1.0, 2.0 and 3.0, the results can be discussed in two categories based on the different concentrations (0.05 g/cc and 0.08 g/cc) used for the Nickel Ferrite Nanoparticle.

At 0.05 g/cc concentration, the following can be observed:

a. From the table of values obtained above, we notice a certain time lapse between initialization at time 0 and when the first reading was taken 240 seconds later. It should be noted that within this time interval, water was being produced due to breakthrough or coning and readings were not taken until the effect of the injection of the nickel ferrite nanoparticles became visible.

b. From Figure1.0, which shows the semi log graph of WOR vs Cumulative Oil production, there is a steady decline in the water oil ratio from 23 to 1.0625, showing that as cumulative oil increases, there is no indication of an increase in water produced. This means that the water-oil ratio in case of a reservoir producing water above its economic limit can experience an impressive decline with the application of Nickel Ferrite nanoparticle, and even other magnetic nanoparticles with similar properties.
c. Also, from Figure 2.0, which shows the semilog graph of WOR + 1 vs Cumulative Oil, there is also a steady decline as Cumulative Oil produced increases, further reiterating the conclusion drawn from Figure 1.0.
d. From Figure 3.0, which shows the semilog graph of WOR vs Time, there is a steady decrease in WOR over time, indicating that the effect of the Nickel Ferrite nanoparticle is not just instantaneous, but progresses with time.
e. Finally, we notice from each case above that the water production does not seize totally. This is desirable as a means of adding to the energy needed to lift the oil from the bottom of the well to the top.

Furthermore, we can determine that if the flowrate at which the nanoparticle is injected or its concentration is increased, its effect in treating wells with high water-oil ratio will be more pronounced.

Also, applying this technique in practices raises some exciting possibilities. For instance, the application of water flood characteristic curves in predicting produced oil, history matching data gotten from the use of nanoparticles in comparison to predicted produced oil without this method will provide staggering contrasts, with the latter method promising an impressive increment in produced oil volume.

The 95.38% decline in water-oil ratio shown in the plots above with respect to both time and cumulative oil produced is impeccable, showing that this innovative technique if applied in practice can yield groundbreaking results.

4.Conclusion

From the study, an experimental setup was designed to carry out the core flooding experiment. Based on the experiment carried out, in the first case for instance (at 0.05 g/cc concentration), the water-oil ratio reduced from 23 to 1.0625 showing an impressive 95.38% decrease over time. The application of these nanoparticles is economical and can provide more income for companies in the sense that when the quantity needed and its effect are checked, there is so much on the upside to suggest remarkable gains.

Nomenclature

WOR	Water Oil ratio
PVA	Polyvinylalcohol
CPCA	Combustion process chemical additives

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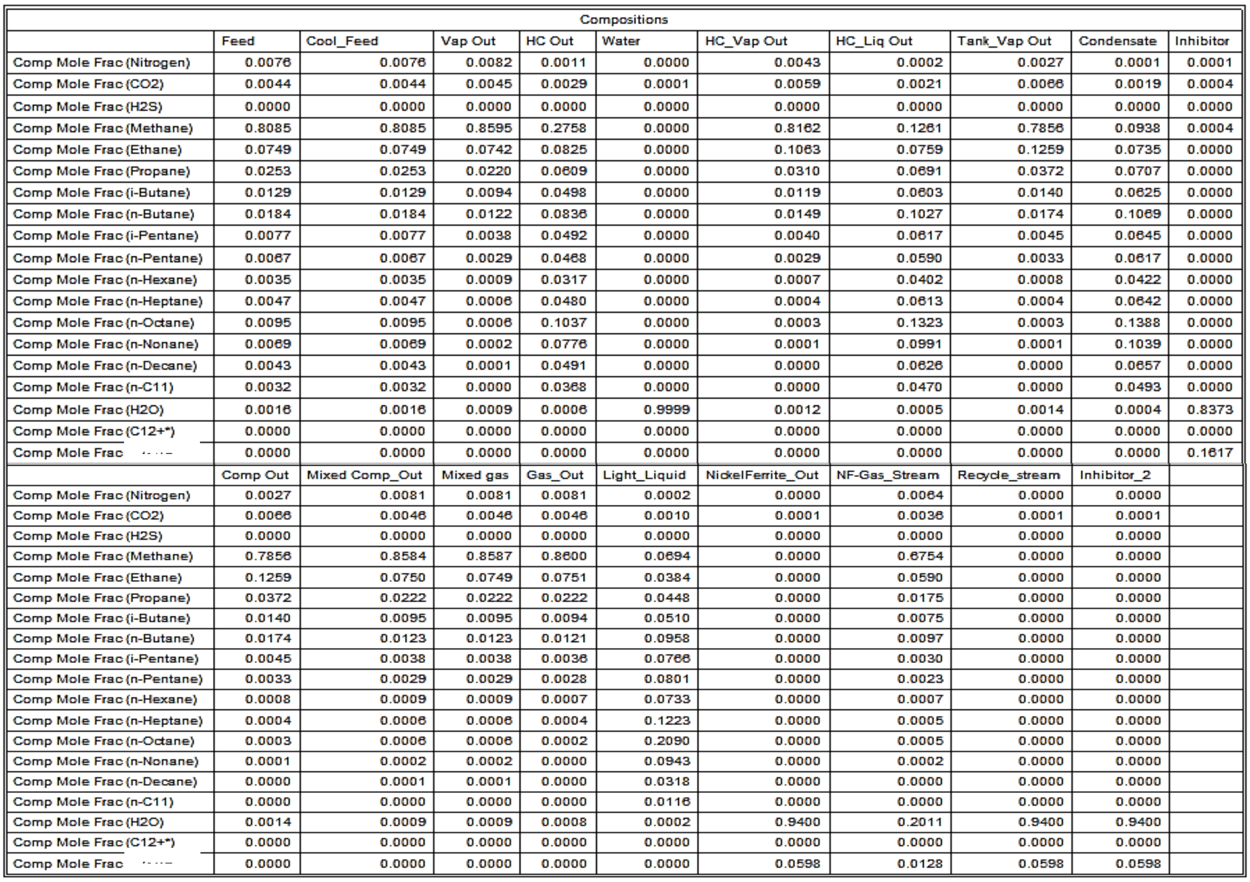
Appendix

Composition of ($NiFe_2O_4$) Nanoparticle



Compositions

	Feed	Cool_Feed	Vap Out	HC Out	Water	HC_Vap Out	HC_Liq Out	Tank_Vap Out	Condensate	Inhibitor
Comp Mole Frac (Nitrogen)	0.0076	0.0076	0.0082	0.0011	0.0000	0.0043	0.0002	0.0027	0.0001	0.0001
Comp Mole Frac (CO2)	0.0044	0.0044	0.0045	0.0029	0.0001	0.0059	0.0021	0.0066	0.0019	0.0004
Comp Mole Frac (H2S)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac (Methane)	0.8085	0.8085	0.8595	0.2758	0.0000	0.8162	0.1261	0.7856	0.0938	0.0004
Comp Mole Frac (Ethane)	0.0749	0.0749	0.0742	0.0825	0.0000	0.1063	0.0759	0.1259	0.0735	0.0000
Comp Mole Frac (Propane)	0.0253	0.0253	0.0220	0.0609	0.0000	0.0310	0.0691	0.0372	0.0707	0.0000
Comp Mole Frac (i-Butane)	0.0129	0.0129	0.0094	0.0498	0.0000	0.0119	0.0603	0.0140	0.0625	0.0000
Comp Mole Frac (n-Butane)	0.0184	0.0184	0.0122	0.0836	0.0000	0.0149	0.1027	0.0174	0.1069	0.0000
Comp Mole Frac (i-Pentane)	0.0077	0.0077	0.0038	0.0492	0.0000	0.0040	0.0617	0.0045	0.0645	0.0000
Comp Mole Frac (n-Pentane)	0.0067	0.0067	0.0029	0.0468	0.0000	0.0029	0.0590	0.0033	0.0617	0.0000
Comp Mole Frac (n-Hexane)	0.0035	0.0035	0.0009	0.0317	0.0000	0.0007	0.0402	0.0008	0.0422	0.0000
Comp Mole Frac (n-Heptane)	0.0047	0.0047	0.0006	0.0480	0.0000	0.0004	0.0613	0.0004	0.0642	0.0000
Comp Mole Frac (n-Octane)	0.0095	0.0095	0.0006	0.1037	0.0000	0.0003	0.1323	0.0003	0.1388	0.0000
Comp Mole Frac (n-Nonane)	0.0069	0.0069	0.0002	0.0776	0.0000	0.0001	0.0991	0.0001	0.1039	0.0000
Comp Mole Frac (n-Decane)	0.0043	0.0043	0.0001	0.0491	0.0000	0.0000	0.0626	0.0000	0.0657	0.0000
Comp Mole Frac (n-C11)	0.0032	0.0032	0.0000	0.0368	0.0000	0.0000	0.0470	0.0000	0.0493	0.0000
Comp Mole Frac (H2O)	0.0016	0.0016	0.0009	0.0006	0.9999	0.0012	0.0005	0.0014	0.0004	0.8373
Comp Mole Frac (C12+*)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Comp Mole Frac	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1617
	Comp Out	Mixed Comp_Out	Mixed gas	Gas_Out	Light_Liquid	NickelFerrite_Out	NF-Gas_Stream	Recycle_stream	Inhibitor_2	
Comp Mole Frac (Nitrogen)	0.0027	0.0081	0.0081	0.0081	0.0002	0.0000	0.0064	0.0000	0.0000	
Comp Mole Frac (CO2)	0.0066	0.0046	0.0046	0.0046	0.0010	0.0001	0.0036	0.0001	0.0001	
Comp Mole Frac (H2S)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
Comp Mole Frac (Methane)	0.7856	0.8584	0.8587	0.8600	0.0694	0.0000	0.6754	0.0000	0.0000	
Comp Mole Frac (Ethane)	0.1259	0.0750	0.0749	0.0751	0.0384	0.0000	0.0590	0.0000	0.0000	
Comp Mole Frac (Propane)	0.0372	0.0222	0.0222	0.0222	0.0448	0.0000	0.0175	0.0000	0.0000	
Comp Mole Frac (i-Butane)	0.0140	0.0095	0.0095	0.0094	0.0510	0.0000	0.0075	0.0000	0.0000	
Comp Mole Frac (n-Butane)	0.0174	0.0123	0.0123	0.0121	0.0958	0.0000	0.0097	0.0000	0.0000	
Comp Mole Frac (i-Pentane)	0.0045	0.0038	0.0038	0.0036	0.0766	0.0000	0.0030	0.0000	0.0000	
Comp Mole Frac (n-Pentane)	0.0033	0.0029	0.0029	0.0028	0.0801	0.0000	0.0023	0.0000	0.0000	
Comp Mole Frac (n-Hexane)	0.0008	0.0009	0.0009	0.0007	0.0733	0.0000	0.0007	0.0000	0.0000	
Comp Mole Frac (n-Heptane)	0.0004	0.0006	0.0006	0.0004	0.1223	0.0000	0.0005	0.0000	0.0000	
Comp Mole Frac (n-Octane)	0.0003	0.0006	0.0006	0.0002	0.2090	0.0000	0.0005	0.0000	0.0000	
Comp Mole Frac (n-Nonane)	0.0001	0.0002	0.0002	0.0000	0.0943	0.0000	0.0002	0.0000	0.0000	
Comp Mole Frac (n-Decane)	0.0000	0.0001	0.0001	0.0000	0.0318	0.0000	0.0000	0.0000	0.0000	
Comp Mole Frac (n-C11)	0.0000	0.0000	0.0000	0.0000	0.0116	0.0000	0.0000	0.0000	0.0000	
Comp Mole Frac (H2O)	0.0014	0.0009	0.0009	0.0008	0.0002	0.9400	0.2011	0.9400	0.9400	
Comp Mole Frac (C12+*)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
Comp Mole Frac	0.0000	0.0000	0.0000	0.0000	0.0000	0.0598	0.0128	0.0598	0.0598	