Volver

Maximizing the Opportunities Offered by Combustion In Situ for the Challenges of the Faja Petrolifera del Orinoco "Hugo Chavez" of Venezuela.

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ABSTRACT

The heavy oil could be considering a great opportunity to investigate and implement upgrading on the traditional thermal technologies for its exploitation. Venezuela has huge considerable reserves of heavy and extra-heavy oil, historically the extraction of these heavy crude oil are based on thermal Enhanced Oil Recovery (EOR)methods to thereby obtain the best benefit on the Recovery Factor. One of the thermal technologies studied for over ten decades with high recovery factors is In Situ Combustion (ISC), which involves injecting air into the reservoir and through an induced ignition generates heat front that promote chemical reactions which aid in oil production. ISC could be visualized like the technology which involves different process simultaneously since vaporization occurs, cracking, distillation, gas production which may improve the physicochemical properties of crude, and its mobility, etc. In order to get the best opportunity from ISC given that it is one of the most protective for the extraction of heavy oil, PDVSA Intevep has been focus part of its efforts to optimize and thus take better advantage of the benefits that it offers. Several experimental studies which main goal is evaluate the effects of emulsified additives to increase and improved the contact with the crude oil, where it has been evidenced that the additives used improves the ISC process (increases the velocity, front stability, etc.) and further the physicochemical properties of crude oil: increase ºAPI, reduction viscosity, etc. why is deemed feasible to be implemented in la Faja Petrolifera del Orinoco, showing a great opportunity to produce heavy and extra oil reserves looming many advantages such as the production of higher value-added enhanced oil, easy handling and transportation in the value chain from reservoir to final delivery point.

KEY WORDS

combustion, viscosity, ºAPI.

INTRODUCTION

It is no secret that Venezuela is a privileged country with immense reserves in heavy and extra heavy oil (American Petroleum Institute) notwithstanding the efficient conversion of this crude oil to commercial fuels remains as a technological challenger for the oil industry and its exploitation motivated to its low fluidity and high viscosity. In this regard have emerged either in the refining field, deep conversion processes address to improve downstream but emerging technologies or from reservoir extraction (CAPRI, THAI, etc.), which may be improving in situ crude minimizing costs production and transport. There are several theoretical proposals described in patents and laboratory studies based on various mechanisms for improvement: solvents injection, hydrogen sources, catalysts, biotechnology, chemical injection, microwave, in-situ combustion (ISC), etc. ISC highlights among this group which has an additional advantage, it is a technology that has been tested and implemented internationally with much success.(1)

This research is aimed to maximize the use of the advantages offered by the ISC process and thus make this the one of the most prospective technology for the production of extra-heavy crude and where the application window and thus obtain higher value crude display added to the market.

In Situ combustion seems to be an appropriate alternative for the production of these crudes as it is a technology that simultaneously increases the recovery factor and sweep efficiency.(2)

ISC is the most efficient and economical thermal method (3), other authors refer, that ISC demonstrated to have some additional benefits: such as a very high thermal efficiency and low costs (4). It is the reason why some authors have focused their effort to optimize this technology (5-8), since this offers a number of advantages compelled its high temperature of heat front, as they are: thermal cracking oxidation, dilution, distillation, vaporization, hydrogenation, thermal expansion, condensation and others.

The present experimental study has as main goal to evaluate In Situ Combustion Process using additives to optimize physical and chemical properties of heavy and extra heavy crude oil which could be potentially implement as a pilot test to the field in Faja del Orinoco Hugo Chavez Frias, in order to improve the recovery factor and upgrading the crude oil. The scope of this study is to evaluate options to optimize the In Situ Combustion process with the incorporation of additives, where the crude oil can get more value-added for the market.

EXPERIMENTAL APPARATUS

The physical displacement tests were performed in a system which included; crude, water and sand from the reservoir into a cylindrical steel cell; it was previously packed with sand trying to emulate reservoir conditions at laboratory scale (porous medium test). The cell configuration has different shots to record the corresponding temperature in this position of the cell and monitoring its variation in time once the test is started. All tests were performed in duplicate in order to validate the results in the cases studied.

Fluids and sand used for the tests (oil, sand from the reservoir and formation water) were previously characterized in order to establish the changes produced once it is carried out the In Situ Combustion process without and additive. To perform ISC tests requires thorough preparation. A detailed description of the process and equipment associated with the process is described following.

COMBUSTION CELL

Combustion cell comprises a cylindrical container constructed from 316 steel with dimensions 30.5 cm in length, 3.8 cm inside diameter, and 0.53 cm wall thickness. The cell withstands high pressures and temperatures (HPHT) and could operate to simulate reservoir conditions at laboratory scale. The test began by packing unconsolidated sand, oil, formation water and the fluid from a heavy oil reservoir, in order to determine the absolute permeability to the air and water. After that effective oil permeability was measured.

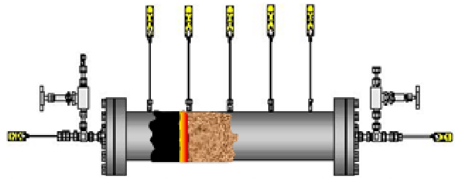
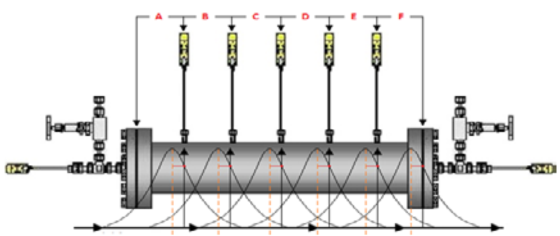


Figure 1: Steel Cell, Sand, Oil and Water in site

Seven electric resistances are placed around the cell, each one with 150 cm in length. The first one is on top to promote the ignition, and the others keep the heat generated in the combustion cell during the test. The cell model facilitates the heat transfer. Also the air injection inside of it and the availability of sensors, spaced equidistant along its length, allow getting the temperature profile, and monitoring the combustion front in real time.

The preparation of the cell is a fundamental part in the execution of a combustion test, which involves several procedures and determines the interval of time between consecutive tests. Generally, this period of time must not exceed one week (4 or 5 days should be sufficient), it began with preparation of the mixture of the hydrocarbon plus the additive or preparation of oil without additive; after it was packing, which made easy the permeability measurements for the fluids (gas, water, oil). Also pore volume, oil and water saturation are carried out before the thermal insulation. The cell isolation is critical, since excessive heat loss generated can promote the extinction of the combustion front. To maintain the combustion process, it is needed that the dissipated heat flux does not exceed the generated heat flow by the reaction. Under adiabatic conditions, it is possible to reduce this effect (loss heat).
In order to have control and monitor continuously the system, the electrical resistances are placed throughout the cell body and then the cell is thermally insulated. After, it is heated on its surface to minimize or annul the temperature gradient generated by the combustion front inside the cell.

Flow controllers allow the system control and regulation of the air injection rate. All generated data by monitoring is recorder every 30 seconds in a PC.



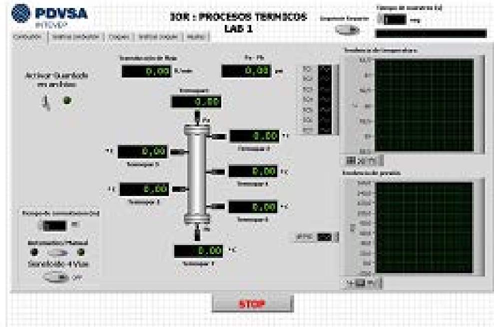


Figure 2: Laboratory: Monitoring the Combustion Front Advanced.

PROCEDURE AND EXPERIMENTAL METHODOLOGY

There is no general consensus about the methodology and the system design for evaluate the ISC process although many groups have been working on it for more than two decades. (9-10). It is still necessary know much about the system and the methodology used in order to establish criteria or improvements that could help future researcher studies in the ISC area.

PDVSA Intevep developed a test system that offer important advantages like is fully automated facilities allowing the data collection, and easy manipulation of the cell due its small size; it measures only 30.5 cm, other additional advantage is the time it takes to perform a test.

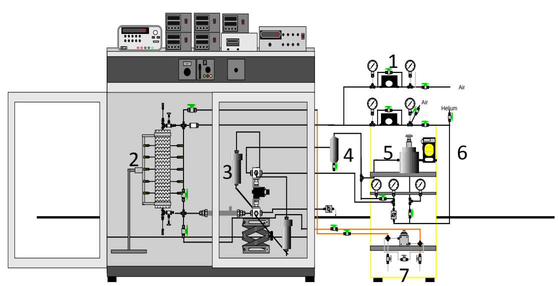
Other important considerations in the design of the equipment are related to the position and direction of air flow inside the cell injection. Mostly, these tests are performed with cell horizontally (4) which could promote gravitational segregation effect. Under this configuration, the air injected could not contact all the oil present in the medium, mainly the bottom part (from a cross-section viewpoint) is not affect by the ISC process. In these conditions the air injection could form fingering inside the cell, and just few amount of oil will be contacted and as a consequence the process efficiency would be lower. This recommendation motivated tests were performed on a vertical form where air is injected through the top promoting the heat front will spread downwards and thus ensure complete contact, the air flow is injected from the bottom above, since by the effect of gravity as they displace crude front down and making contact with the hot sand and coke forming and covering sweep system.

The tests conditions were established regarding to the area of study at the field (sand, pressure, temperature, permeability, from the reservoir, etc.); and this sense would be possible to upscale the performance of the ISC process test to the field, providing an idea of the behavior of the important variables to be taken into account: amount of air required, consumed and recovered oil, etc.

Three runs using crude 8.1 ºAPI from Orinoco Oil Belt were carried out, always keeping reservoir conditions. The first tests were reference; the following 2 trials were performed with additive and were evaluated as an alternative to improve heavy oil properties. All the experimental test were conducted under similar conditions, including air flow rate of 0.9 slpm and the reservoir defined equal to 1000 psia. The sand was packed in the cell, with a porosity of 30%, oil and water saturation of 88% and 12%, respectively. The system was placed inside an oven and heated to reservoir temperature. After that, helium was injected to open a preferential path and thus avoid high differential pressure zone. Then, the ignition started when the temperature reaches 400 ºC. The air injected rate was 0.9 slpm (11) and helium injection in the cell was suspended. The beginning of combustion was indicated by the increase in the temperature sensors which were monitored in the console, the igniter was turned off when the combustion front passed through the first temperature sensor, the temperature generated was maintained adiabatically by the other resistances. When the combustion front passed for the last heat sensor the air was suspended.

Before performing analysis it was determined the water content that accompanies each sample in order to verify the mass balance and to avoid any undesirable effect on the results. These results were used directly to evaluate the performance of the test and were also required for the calculation of recovery factor.

The remaining oil contained in the sand was cleaned using a reflux column system in series with solvent (usually dichloromethane).



1 Flow Valve　　4 Condenser　　7 Pressure Transducer
2 Cell　　5 Pressure Control Valve
3 Collector Cylinder　　6 Flowmeter

Figure 3: Laboratory: Schematic Experimental Apparatus.

RESULTS

All tests were conducted under similar conditions (pressure, temperature, etc.), the only variant that the test 1 was dry combustion conventional procedure, the test 2 and 3 were using an additive.

The following tables present the tests conditions, the characterizations of the fluids used and the mineralogical composition of the sand.

Table 1: Combustion Run Conditions

	Test 1	Test 2	Test 3
Sand	**Reservoir**	**Reservoir**	**Reservoir**
Porosity (ml)	115.27	118.28	117.00
Porosity (%)	34.03	34.92	33.40
Permeability N_2 (Darcy)	4.86	4.01	4.10
Permeability H_2O (Darcy)	3.46	2.73	2.89
Permeability Oil (Darcy)	3.39	2.19	2.20
S_w (%)	8.37	16.88	8.45
S_w (gr)	9.63	20.42	9.89
S_o (%)	91.62	83.11	90.79
S_o (gr)	105.36	100.57	106.23

Table 2: Properties and Oil Composition

Analysis	Value
Viscosity a 50ºC (cP)[a]	33.020
Composición SARA (%mas)	
Saturated	11.8
Aromatic	47
Resins	26
Asphaltenes	14.6
Sulfur conten (%wgth)	3.48
Nickel content(ppm)	94
Vanadium (ppm)	392
API Gravity	8.5

Table 3: Properties and Water Composition.

Analysis	Formation Water
Viscosity at 50ºC (cP)[a]	0.95
Alkalinity (ppm $CaCO_3$)	1270
Cations (ppm)	
Al^{3+}	< 1.00
Ca^{2+}	110
Fe	< 1.00
K^+	160
Mg^{2+}	44
Mn	< 1.00
Na^+	3650
Anions (ppm)	
Cl^-	5255
NO_3^-	< 25
SO_4^{2-}	741
CO_3^{2-}	< 10
HCO_3^-	1550

Table 4 : **Sand Composition**.

Components (%w)	
Fe	**0.4**
SiO_2	**86**
Al_2O_3	**0.8**
C	**0.5**
S	**0.3**

Table 5**:** Combustion Front Velocity

Test	**1**	**2**
Time (cm/h)	**12.1**	**20.5**

Table 6**:** SARA Test 1

	Flash1	Flash2	Flash3	Flash4	Flash5	Flash6
Saturated	6	6	6	9	13	12
Aromatic	42	40	44	34	46	38
Resins	37	41	38	49	33	46
Asphaltenes	15	13	12	8	8	4

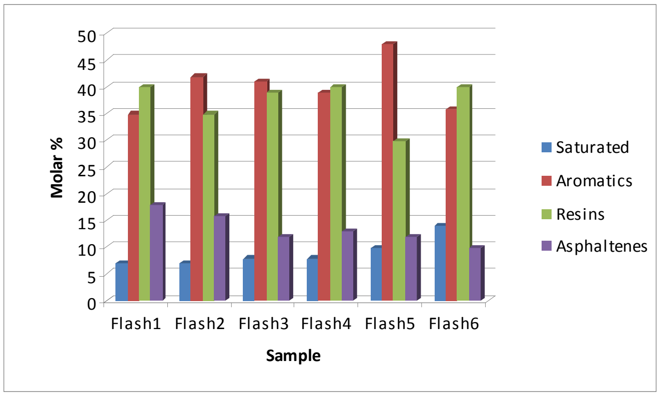


Figure 4: SARA Test 1

Table 7: SARA Test 2

	Flash1	Flash2	Flash3	Flash4	Flash5	Flash6
Saturated	7	7	8	8	10	14
Aromatics	35	42	41	39	48	36
Resins	40	35	39	40	30	40
Asphaltenes	18	16	12	13	12	10

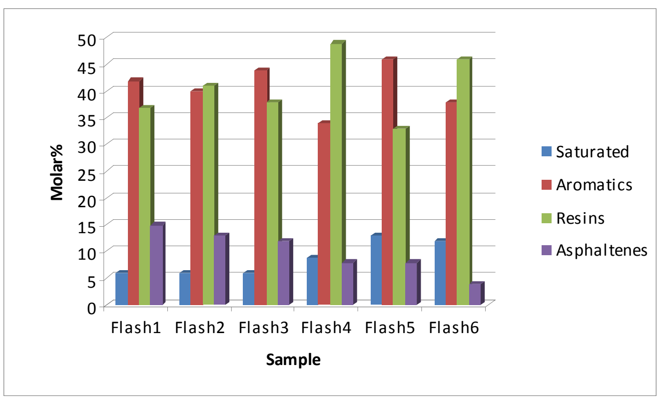


Figure 5: SARA Test 2

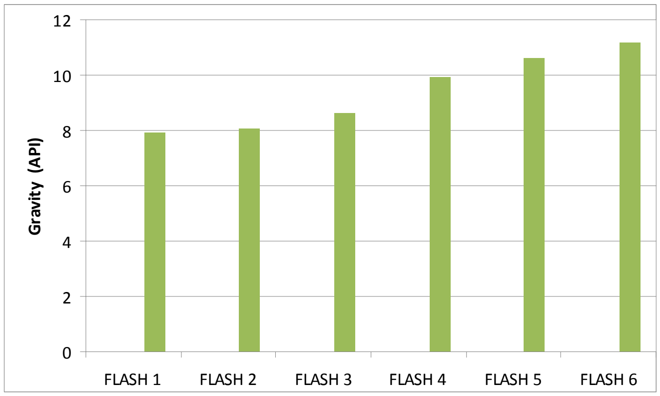


Figure 6: ºAPI Test 1

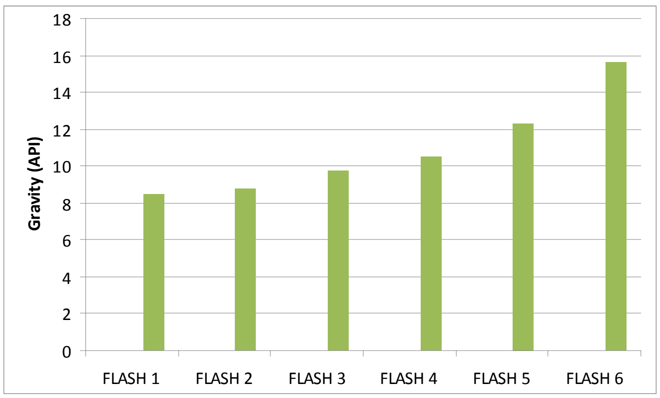


Figure 7: ºAPI Test 2

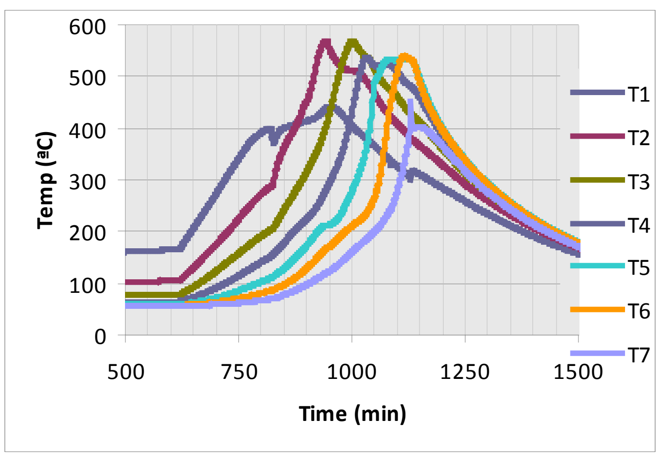


Figure 8: Temperature Profile Test 1

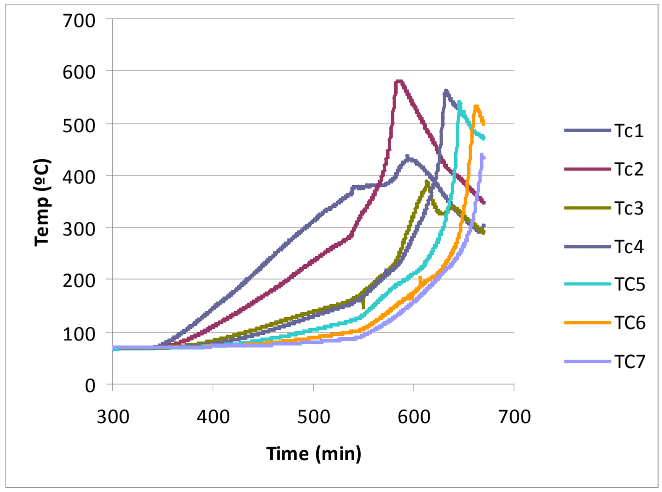


Figure 9: Temperature Profile Test 2

The tests 1 and 2 are associated to evaluate an additive to upgrade physicchemical properties of the crude oil produced. In other hand, the test 3 considers the prelimirany evaluation of an additive for mitigating H_2S at the reservoir.

The results for the test 3 are compared with the test 1 which is considered the Control Test (Test 1).

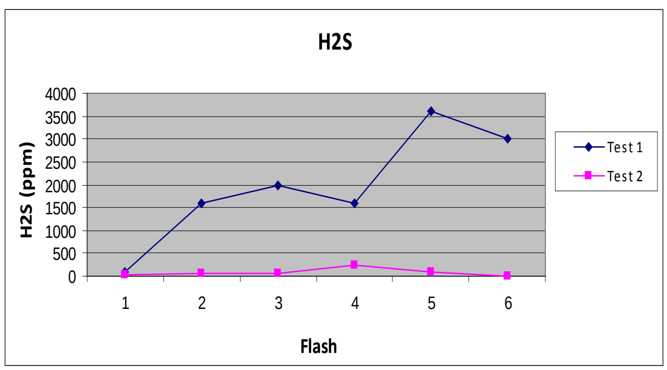


Figure 10: Profile H_2S Test 1 y 3

Table 8**:** Generated Gases from Test 1

	% Molar
Methane	0.290
Ethane	0.080
Propane	0.040
Butane	0.003
Pentane	0.020

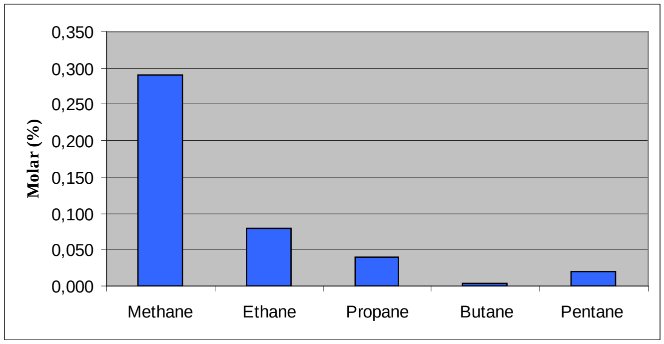


Figure 10: Gases generated for the Profile Test 1

Table 9**:** Generated Gases from Test 2

	% Molar
Methane	0.19
Ethane	0.08
Propane	0.06
Butane	0.01
Pentane	0.02

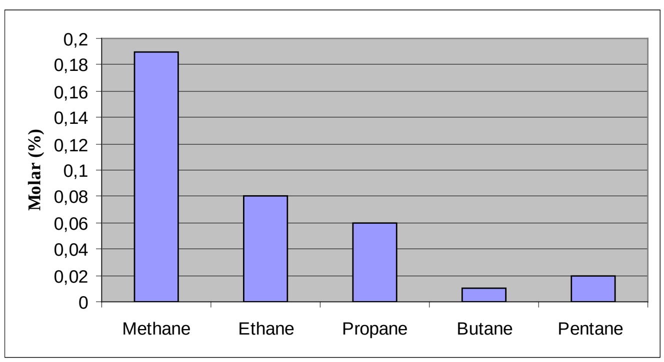


Figure 11: Figure 10: Gases generated for the Profile Test 2

DISCUSSION

Velocity: in Table 5 front velocity values are reported. The values obtained from the tests 1 and 2 evidence that the used of additive has an important influence on the front velocity parameter. A faster front (test 2) was observed an additional benefit which is obtained as oil production would be faster, and the reason for velocity of the test 1 was slower than test 2 it could be associated with the requirement to burn on this case was more fuel to maintain combustion front.

SARA: The Figures 4 (test 1) and 5 (test 2) it can observe how were the gases production during the development of these tests; it was determined that in the test 1 maintained a very similar behavior to the test 2. However, in test 1 aromatics and asphaltenes decreases leading to more and more light formation compounds and coke production. This means that these heavy molecules joined together in large clusters to form coke and maintain the combustion front, which could be considered as a important benefit; but the test 1 needs more fuel to keep the front through time, and the test 2 did not require much fuel for the front to stay during the time.

ºAPI: In the Figures 5 (test 1) and 6 (test 2) can be seen as ºAPI is affected by the combustion process, this parameter is an important factor as the price of crude oil is defined based on it, at higher API greater market value.

Upon study on conventional In Situ Combustion (ISC), it was demonstrated that the combustion process increases API gravity of the oil produced; it is an additional reason for implementing this process. Besides when the additive with ISC is applied there is a further improvement as the front advanced which showing that it can be optimized the ISC process combustion to obtain higher profit.

Temperature profiles for tests 1 and 2: Historically thermal methods of EOR are applied for viscous crude oil as it is the most practical method for displacing through allowing lower viscosity to the oil and therefore its mobility increase into the reservoir.

As shown in Figure 7 and 8 the temperature profiles are important when a ISC process would be applying into the reservoir specially heavy oil, during this study with and without additive the peak of temperatures obtained remaining in the same range, for that reason it was determined that the additive does not affect this variable; which could be considered positive since no more oxygen is required to maintain the front and thereby the requirement of surface installations and their capacity do not need any further inversions

H_2S: One of the main concern and commitment is with environment regulations. The mitigation of pollutant gases when a thermal EOR project is implemented should be consider to protect our world and the people on it; additional environmental regulations have enabled awareness to guide the production of more environmentally friendly fuel. The hydrogen sulfide, which is one of the most hazardous gases produced during thermal EOR methods, and should be a need either to mitigate its production or control under current regulations. In this order, another big advantage with the additive use for the production of these crudes oil by thermal methods should be the potential mitigation underground; it could reduce the production of H_2S.

The results obtained on Figure 9, for the test 3 which was carried out to evaluate just its the potentiality to mitigate H_2S; show an interesting and very prospective use of the additive, to reduce significantly the amount of H_2S. From the chart it is possible to observe how the point 5 reduced H_2S from 3600 to 100 ppm from the downstream of the ISC process. In other hand, it would be traduce on important savings in use of infrastructure to handle large amounts of this contaminant.

Generated Gases: Hydrocarbon Gas production can be visualized in the graphs 8 and 9 giving an idea of the additional benefit and the opportunity from apply of ISC processes in place, as these gases are susceptible to condense downstream of the process and diluting the oil and therefore increasing the oil mobility and thus accelerating the production; it could be observed with the tests with and without additive do not notice any difference.

CONCLUSION

The studied carried out with the incorporation of additive in ISC process evidences the possibility to maximize the opportunity of the ISC process.

The use of additive increases the velocity front without affecting the requirement either of fuel or oxygen.

The tests without additive requiring more fuel to maintain the combustion front through time.

The ISC tests with and without the additive increases ºAPI , but adding additive to the ISC process; the tendency to increase as the front advances, is higher and a crude oil with more added value to the market is obtained

Temperatures profiles are not affected by the use of additives since they are similar to conventional test, being positive, as no more oxygen is needed with the use of an additive to keep the front.

In a conventional ISC test, H_2S emissions are very high, but with the additive was demonstrated that it is possible to mitigate it.

The gases generated during the tests with and without additive showed that the ICS process offer an additional benefit as these may condense to dilute the crude downstream thereby increasing their mobility.

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NOMENCLATURE

ppm	= part per million
Sw	= water saturation
So	= oil saturation
T1,T2, T3, T4, T5, T6	= peak temperature for each test, T1 (°C), T2 (°C), T3 (°C), T4 (°C), T5 (°C) y T6 (°C)
SARA	= saturated, aromatics, resins, asphaltenes
Flash	= sample
ISC	= in situ combustion
O_2	= oxygen
Subscripts:	
o	= oil
w	= water

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