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Heavy Crude Oil Upgrading: Jazmin Crude

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ABSTRACT

The Jazmin crude oil is located at the heart of Middle Magdalena in Colombia. It is heavy and sour crude oil with 43 wt.% of vacuum bottoms. It cannot be processed at the conventional refinery without being mixed with other lighter crudes, and should be upgraded to produce synthetic crude with higher concentration of distillates and lower acidity and carbon content. In this paper eight upgrading alternatives are presented. The alternatives include the processing of the crude, reduced crude and vacuum bottoms of the Jazmin crude oil using the following technologies: Distillation, solvent deasphalting, visbreaking, Delayed Coking, and Hydrotreating. The experiments were conducted at pilot scale, and there were used standard analysis techniques such as ASTM. In this study it was found that Jazmine crude oil and its heavy components produce high distillate yields when they were processed with thermal conversion processes. In addition those processes reduce the products acidity. Within the analyzed scheme the one corresponding to the visbreaking of the crude oil and the Delayed Coking of the vacuum bottoms from the visbreaking is perhaps the most attractive, giving 5.9 wt.% of gas, 78.2 wt.% of distillates and 15.9 wt.% of coke.

Keywords: Jazmin Crude; Upgrading; Visbreaking; Deasphalting; Coking; Thermal Conversion; Heavy Crude; Acidity

1. Introduction

The depletion in reserves of light and medium crude oils has focused interest in heavy oils [1,2]. Furthermore, there is currently high demand for 20˚ - 25˚ API quality crude oil because the production of Maya and other similar crude oils has been declining in recent years. Exports of Maya crude oil have decreased by about 1 million of barrels per day over the past seven years [3].

Crude oils located in the Middle Magdalena region of Colombia, such as Teca, Nare and Jazmín, are typically viscous and therefore require diluents for their transport by pipeline. They are considered as heavy crude oils. These crude oils do not have high concentrations of coke promoters, so they are sometimes mixed with a pool of crudes suitable for submission to a conventional refining process. However, they are characterized by high acidity (NN > 3.9 mg KOH/g of oil), which is a problem for transportation and refining. An important aspect of the implementation of the thermal processes to acid crudes is that they eliminates or substantially reduces its acidity [4, 5].

Heavy crude oils like Jazmin are cheaper and have lower profits per barrel than conventional oil. However, their refining margin could be improved if they are properly handled. For such a purpose, the conventional processes are based on carbon rejection, hydrogen addition or processes with both technologies [6-12]. Carbon reject technologies includes processes such as visbreaking, thermal cracking and coking while hydrogen addition technologies are classified depending on the type of the reactor used.

In the group of carbon reject technologies, delayed coking and fluid-bed coking continue to be the major process route for producing distillates from vacuum bottoms [13]. Delayed coking (DC) is a thermal process which converts vacuum residue or other residue feedstocks into gas, light products and petroleum coke. DC distillates have a large proportion of olefins which under conditions of temperature, residence time and pollutants tend to polymerize forming gums and degrade their quality. To control these reactions, the DC liquid effluents should undergo hydrotreating processes which stabilize them by the saturation of their double bonds. The coke production ranges from 18 to 30 wt.% of the residual oil, depending on the composition of the feedstock and the operating conditions.

Fluid-bed coking is a continuous process where petroleum coke is combusted to provide process heat, avoid-

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ing the used of fuel or natural gas as used in DC. With fluid-bed coking results three are lower coke yields, higher liquid and gas production than with DC.

Visbreaking (VBR) is probably the lowest cost conversion technology. It is a thermal cracking process at low temperatures to reduce the viscosity of the feedstock and produces gases, naphtha and fuel oil and in some cases gas oils which can be used as feedstock for Fluid Catalytic Cracking (FCC). Usually the VBR feedstock is constituted by vacuum bottoms with CCR of 20 wt.% but in some cases it consists of pitch with CCR of 40 wt.%.

Solvent deasphalting process (SDP) is still having high importance in the world [14-16]. SDP is a physical separation process by means of a solvent. Its products are deasphalted oil (DAO) and pitch or deasphalting bottoms (DAB) rich in aromatics with high concentration of impurities such as metals (Ni, V), sulfur, asphaltenes and Conradson carbon. The DAO can either be used for the production of lube oil and paraffinic waxes or as feedstock for the FCC process or for the hydrocracking. The DAB is used either to prepare asphalt or as feed to the visbreaking process. Pitches like DAB had been generally expected to have processing problems in the delayed Coker as unstable feeds due to the concentrated asphaltenes and double bonds.

Foster Wheeler had patented the integration of SDA and DC and claimed that there was a synergistic benefit from combining these two technologies that produced a lower coke yield. The technology is marketed by Foster Wheeler as the ASCOTSM process [16]. The effort to improve these processes continues as it is shown in the works of Bjoror O. for the precipitation of asphaltenes from Athabasca bitumen using α,α,α-trifluorotoluene [17].

2. State of the Art

Heavy crude oils are the alternative to supply refineries in the world. At present heavy crudes of the Orinoco and those from Canadian tar sands undergo upgrading processes to produce synthetic crude oils, which are already commercialized [18]. The main problem for upgrading heavy crude oils is their high concentration of carbon within the vacuum bottoms, however, the heavy crude oil from the Middle Magdalena despite being viscous have low levels of coke promoters (Vacuum bottoms with CCR 17.9 wt.%, and insoluble in n-C_7 4.6 wt.%), which made them suitable for either a process of Delayed Coking (DC) or hydrotreatment (HDT). Thermal processes break down the molecules that cause acidity [17], so the distillates of a Delayed Coking technology should present low values of NN, compared with the same of the original oil.

For crude oil vacuum bottoms handling, the processing facilities installed at the conventional refinery allow the production of asphalts for the pavement of the roads as well as the production of fuel oil, diluting the vacuum bottoms with appropriate solvents or by vacuum bottoms visbreaking. However, the fuel oil consumption in the world is going down and the refinery should be located near shore to facilitate it shipping.

For the upgrading of these crudes different technologies are combined such as fractionation, SDP, thermal cracking (DC and VBR), and HDT mainly. As a result of the application of these technologies, relatively light crudes with low levels of vacuum bottoms, high concentrations of middle distillates and stable diesel, and low sulfur concentrations, low NN, and low nitrogen concentration are obtained. These characteristics allow their use as part of the pool of crudes to a refinery and thus increase middle distillates yields such as diesel and Jet.

3. Experimental

For the upgrading of Jazmin crude oil, operational schemes that combine commercial technologies, using as raw material either crude oil or reduced crude or vacuum bottoms were studied. These cuts were obtained by Jazmin crude oil ASTM distillation. The distillation yields and the properties of the Jazmin crude oil are given in the **Table 1**, column 2. The yields of refined cuts are: atmospheric distillates 19.6 wt.%, and vacuum distillates 35.1 wt.%, so the amount of vacuum bottoms are 45.3 wt.%.

The runs were carried out at pilot plants designed and built in ECOPETROL-ICP [19-22]. The analyses were performed following ASTM methods in the laboratories of ECOPETROL-ICP, certified by ISO 9001.

The operating conditions used in the pilot plants were:

1) For Delayed Coking: load 2000 g, temperature 510˚C, pressure 10 psig and run time of 2 h.

2) For Visbreaking: temperature 480˚C and residence time 60 seconds.

3) For Solvent Deasphalting: Solvent/Feed ratio was 6/1 vol/vol, the bottom temperature 60˚C and the top temperature 100˚C. The solvent used for deasphalting was nC_4.

The analyzed operational schemes for the upgrading of the Jazmin crude oil were:

1) Processing of the crude:

a) Visbreaking (VBR) of the crude and Delayed Coking (DC) of the Visbreaked vacuum bottoms.

b) nC_4 Crude Deasphalting and DC of its Demetallized oil (DMO), and

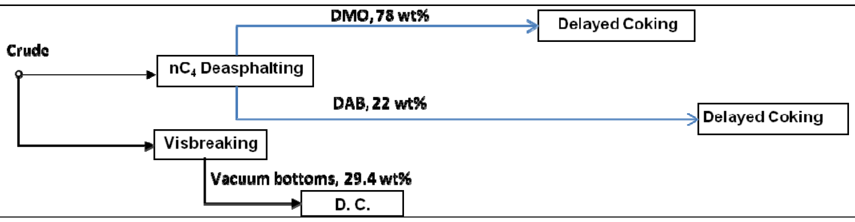
c) nC_4 Crude Deasphalting and DC of the bottoms from Deasphalting (DAB).

2) Processing of the reduced crude:

a) nC_4 Solvent deasphalting of the reduced crude and DC of the bottoms from deasphalting, and

b) Delayed Coking of the reduced crude.

Table 1. Alternatives for the upgrading of the crude Jazmín.



1	2	3	4	5	6	7	8	9	10
		Visbreaking			**Deasphalting and DC of the DMO**			**Deasphalting and DC of the DAB**	
Atmospheric Distillation	**Crude**	**Visbreaking**	**DC of the visbreaking bottoms**	**VB of the crude, and DC of the bottoms from the VB**	**Crude Deasphalting**	**DC of the DMO**	**Deasphalting and DC of the DMO**	**DC of the DAB**	**Deasphalting and DC of the DAB**
Gases		**2.14**	**12.7**	**5.9**		**10.5**	8.2	**6.6**	1.5
Naphthas		12.3	18.9	14.3		19.0	12.2	16.8	2.2
Jet	2.54	1.7	8.3	2.6		11.0	7.0	8.2	1.1
Diesel	7.18	24.9	12.5	26.3		18.0	11.5	14.3	1.9
AGO	9.92	11.3	11.8	12.6		17.0	10.9	14.5	1.9
Vacuum distillation									
LGO	12.18	12.4	13.3	13.8		16.0	10.2	16.6	2.2
MGO	12.85		13.3	1.4		12.0	7.7	15.3	2.0
HGO	10.03	4.8	16.5	6.6		5.0	3.2	11.1	1.5
Vacuum bottoms	**45.3**	29.4	5.4	0.6		2.0	1.3	3.2	0.4
DMO					**78**				78
DAB					**22**		22.0		
DC Distillates			**36.8**			**82.1**		**60.5**	
Coke		1.1	**50.5**	**15.9**		**7.4**	5.8	**32.9**	7.2
Total	**100**	**100**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

DC—Delayed Coking; VB—Visbreaking; DMO—Demetallized Oil; DAB—Deasphalter bottoms.

3) Processing of the vacuum bottoms:

a) Delayed coking of the vacuum bottoms.

b) nC$_4$ Deasphalting of the vacuum bottoms, and DC of the deasphalting bottoms.

c) Visbreaking of the vacuum bottoms.

4. Results and Analysis

4.1. Processing of Crude Jazmín

For the upgrading of the Jazmín crude the schemes presented in the **Table 1** were considered:

4.1.1. Visbreaking of the Crude and Delayed Coking of the Visbreaked Vacuum Bottoms

In this scheme, the crude Jazmín is subjected to the visbreaking process (column 3 of **Table 1**), and the visbreaked vacuum bottoms corresponding to 29.4 wt.% of the crude oil are subjected to DC.

In the column 2 of **Table 1** is shown the composition of Jazmín crude oil; column 3 shows the yields of visbreaked crude. It is clear that the achieved conversion in the visbreaking process of the crude is high as the vacuum bottoms are reduced from 45.3 wt.% in the virgin crude to 29.4 wt.% in the visbreaked crude. That means a conversion of 35.1 wt.%. Moreover, vacuum distillates are reduced from 35.1 wt.% to 17.2 wt.%. That means a conversion of 51 wt.%. As a result of this conversion atmospheric distillates are increased from 19.6 wt.% to 50.2 wt.%.

In the fourth column **Table 1** in bold are given the yields corresponding to the DC of the visbreaked vacuum bottoms, and in normal is given the simulated distillation of the DC distillates. Although the feedstock to the DC is a visbreaked product, the coke production is relatively low and corresponds to 50.5 wt.%.

In the fifth column of **Table 1** is given the composition of the synthetic crude corresponding to the studied scheme. The yield of diesel is quiet high, 26.3 wt.%, of which most is produced in the visbreaking. In addition, it was found that the vacuum bottoms from the visbreaked Jazmín crude have a relatively high conversion capacity in the DC process. The yield of coke regarding the visbreaked vacuum bottoms is 50.5 wt.% and regarding the synthetic crude of the scheme is 15.9 wt.% (columns 4 and 5).

This is a scheme that reduces the amount of diluents for the transport and it requires low investment in upgrading technology, because DC processes only 29.4 wt.% of the crude oil. Both distillates (from the Visbreaking and from DC) are unstable and required treatment with hydrogen.

As reference for comparison in the first column of the **Table 2** are given the properties of the vacuum bottoms from the virgin crude. The promoters of coke increases significantly in the visbreaked vacuum bottoms as follows: CCR goes from 17.9 wt.% to 34.9 wt.% (an increase of 95 wt.%), and asphaltenes from the SARA analysis goes from 14.5 wt.% to 19.4 wt.% (**Table 2**). For this reason, the coke yield in the process of visbreaked vacuum bottoms DC is high, and reaches 50.5 wt.%, a value that agrees with the rule of thumb on expected coke (1.5 × CCR = 52.4% m).

Another important aspect of this scheme is the acidity reduction as it is shown in the case of the vacuum bottoms. In the crude oil vacuum bottoms NN was 3.93 mg KOH/g of oil, and in the visbreaked vacuum bottoms was 0.8 mg KOH/g of oil. That result confirms that thermal processes reduce the acidity of the feedstock.

4.1.2. nC_4 Crude Deasphalting and Delayed Coking of the Demetallized Oil (DMO)

The yields of nC_4 crude oil Deasphalting are 78.0 wt.% of DMO and 22.0 wt.% of bottoms (DAB, **Table 1**, column 6). Within the same table, in the column 7 in bold the DC yields are given (gas: 10.5 wt.%, distillates: 82.1 wt.%, and coke: 7.4 wt.%), which totalize 100%. The others results correspond to the simulated distillation of the DC distillates, which also correspond to 100%. Because the promoters of coke have been removed from the feed in the previous process of Deasphalting, coke production in the last process is only 7.4 wt.%. The CCR in the feedstock to the DC process is 4.4 wt.% as can be seen from **Table 2**, so the amount of coke is 1.6 times de amount of CCR in the feedstock. The sum of Jet and Diesel is 23.8 wt.% and the yield of naphtha is 15.6 wt.%. Within the distillates, the yield of atmospheric distillates is 65 wt.% and the yield of vacuum distillates is 33.0 wt.%.

In the consolidate of the synthetic crude is shown a coke production of 5.8 wt.% regarding to the original crude (column 8 of **Table 1**), which is a rather low value for the upgrading schemes, however, it should be taking in account the production of 22.0 wt.% of bottoms from deasphalting (DAB), with which the bottoms yield gives a total of 27.8 wt.% respect to the crude oil. DC distillates should be processed in HDT for their stabilization.

This is a scheme of high production of naphtha and high-capacity of the upgrading.

4.1.3. nC_4 Crude Oil Deasphalting and Delayed Coking of the Bottoms from the Deasphalting

The yields from the DC of the deasphalting bottoms are presented in the column 9 of **Table 1** and the composition of the consolidated synthetic crude is given in the column 10. Coke production in the DC of the deasphalting bottoms is 32.9 wt.%, which is a rather low value considering that the DC feed correspond to the bottoms from the Deasphalting, however, according to the rule of thumb, the expected coke yield is 1.5 * CCR in the feedstock, It means 30 wt.%.

In the consolidated scheme the coke yield is 7.2 wt.% and the main product is the DMO with a yield of 78 wt.% (column 10).

This is the scheme that produces the less quantity of solids (coke or bottoms from the Deasphalting process). It is also a low investment process with an average conversion, providing feed to the FCC process. DC distillates require hydrotreating.

4.2. Processing of the Reduced Jazmín Crude 370˚C+

The reduced crude is 80.4 wt.% of the whole crude. The analyzed schemes are (**Table 3**):

1) nC_4 Solvent deasphalting of the reduced crude and DC of the bottoms from Deasphalting, and

2) Delayed Coking of the reduced crude.

The product quality of the studied schemes is presented in the **Table 4**.

4.2.1. nC_4 Solvent Deasphalting of the Reduced Crude and DC of the Deasphalter Bottoms

In the column 2 of **Table 3** in bold are given the yields of the Deasphalting process, and the others results correspond to the DMO composition. In the column 3 the composition of the bottoms from the Deasphalting process is given. In the column 4 the yields of the DC of the deasphalter bottoms are given. In the column 5 the composition of the synthetic crude is given.

Regarding reduced crude, the DMO yield is 69.5 wt.%

Table 2. Quality of the products from the upgrading of the crude Jazmín.

	Vacuum Bottoms	Visbreaked Vacuum Bottoms	DC of VBR vacuum bottoms	DMO	DAB	DC of DMO	DC of DAB
Density at 5˚C, g/cm^3	1.0262	1.0745	0.9395	0.9684	1.049	0.92	0.925
API	6.3	0.1	19		3.3		21.3
CCR, wt.%	17.9	34.9	4.9	4.4	20	2.2	1.97
Sulphur, wt.%	1.7	2.1	1.6	1.5		1.3	1.646
Ashes, wt.%	-	0.458					
Ca, ppm	2666.0	1128		54.4	1109		
Ni, ppm	130.7	213		17.379	214.88		
V, ppm	167.27	243		15.684	280.7		
Na, ppm	38.5	29					
Ni + V, ppm	298.0	456		33	496		
Refractive index				1.5184			
i-nC$_7$, wt.%	4.6	25.7			16.25		
i-nC$_5$, wt.%	11.3	32.3			36.07		
Viscosity-1, cP	30800 @100˚C	225000 @120˚C		33			
Viscosity-2, cP	4950 @120˚C	69500 @130˚C		82 @80˚C			
Basic N, wt.%	0.284	0.4	0.2	0.124	0.389	0.11	0.18
Total N, ppm	7451	1.2	6130	3679			5302
N.N, mg KOH/g	3.93	0.8					
SARA analysis, wt.%							
S	8.9	5.3					
A	55.2	45.3					
R	21.4	30.0					
A	14.5	19.4					

VBR—Visbreaked; DC—Delayed Coking; DMO—Demetallized Oil; DAB—Deasphalter bottoms.

and the deasphalting bottoms yields are 30.5 wt.%. Within the DMO, 37 wt.% are vacuum bottoms. This result corresponds to low concentration of CCR within the feedstock (11.2 wt.%). Within de DAB, the main component correspond to the vacuum bottoms (75 wt.%, column 3 of **Table 3**).

The Delayed Coking of the DAB produces 31.7 wt.% of coke, which is a low value considering that the feed is deasphalter bottoms and this is due to the low concentration of coke promoters within the feed stock (CCR = 26.3 wt.%, **Table 4**) and to the fact that many of the components of the CCR are soluble in cyclohexane [23]. According to the rule of thumb, the expected coke is 39.45 wt.%.

In the consolidated scheme (synthetic crude oil—column 5 of **Table 3**), coke production is only 7.8 wt.%.

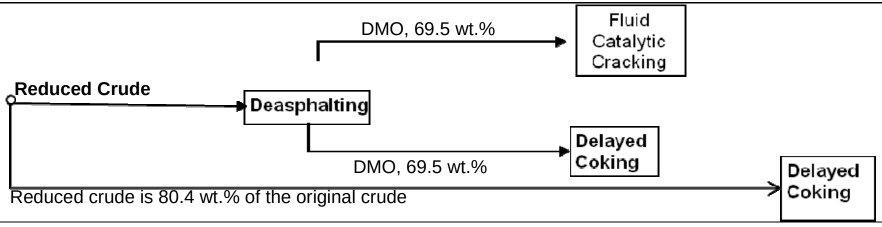
The main processes in this scheme are physical separations, and the conversion is very low and corresponds to the DC process. The upgrading costs in this scheme are low. This is because in the DC is processed only 21.2 wt.% of the feedstock. The vacuum bottoms are reduced from 45.3 wt.% to 21.5 wt.%. That is a substantial reduction. DC distillates must be subjected to hydrotreating. The metals concentration within the DMO is normal for the FCC feedstock or for its Hydrocracking.

4.2.2. Delayed Coking of Reduced Crude

In the column 6 of **Table 3** in bold are given the delayed Coking yields of the reduced crude, and the other results correspond to the composition of the DC distillated.

In this alternative the production of coke is very low (11.7 wt.% with respect to the virgin crude—**Table 3**,

Table 3. Alternatives for the upgrading of the Jazmín reduced crude oil.



	1	2	3	4	5	6	7
		Deasphalting of the reduced crude and DC of the bottoms from the Deasphalting				**DC of the reduced crude**	
		Deasphalting and DMO composition	**Bottoms from Deasphalting**	**Delayed Coking of the DAB**	**Sintetic Crude from the scheme**	**DC of the reduced crude**	**Synthetic crude from the scheme**
Atmospheric distillation	**Crude**						
Gases				9.2	2.3	**12.1**	9.7
Naphtahs				10.6	2.6	20.0	11.7
Jet	2.5			4.1	3.6	8.0	7.3
Diesel	7.2			7.1	8.9	11.0	13.7
AGO	9.9	9.0	3.0	8.3	17.0	14.0	18.2
Vacuum Destilation							
LGO	**12.2**	16.0	4.0	8.3	11.0	18.0	10.6
MGO	**12.9**	26.0	9.0	11.2	17.3	16.0	9.4
HGO	**10.0**	12.0	9.0	5.9	8.2	13.0	7.7
Vacuum bottoms	**45.3**	37.0	75.0	3.5	21.5	0.0	0.0
DC Distillates						**73.4**	
DMO		**69.5**					
Bottoms from Deasphalting		**30.5**					
Coke				31.7	7.8	**14.5**	11.7
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

DC—Delayed Coking; DMO—demetalized Oil; DAB—Bottoms from Deasphalting.

column 7), and the conversion is high, especially to middle distillates (Jet + Diesel), which goes from 9.7 wt.% in the original oil to 21.0 wt.% in the synthetic crude. The vacuum bottoms are totally converted. According to the rule of thumb, the expected coke was 1.5 * CCR within the feedstock, it means 16.8 wt.%, and the explanation for this behavior consist in the fact that many components of the CCR are soluble in cyclohexane [23].

This alternative produces high yields of atmospheric distillates; it is costly because it involves processing all reduced crude, which accounts 80.4 wt.% of the whole crude. Distillates from DC must be subjected to hydrotreating.

When comparing the quality of the studied schemes products (**Table 4**), we observed expected behaviors. The Ni + V concentration within the DMO is 31.2 ppm, so we should consider it hydrotreating to adequate feed to catalytic cracking process.

4.3. Processing of the Vacuum Bottoms from the Jazmin Crude Oil

The analyzed schemes were (**Table 5**):

1) Delayed coking of the vacuum bottoms.

2) nC_4 Deasphalting of the vacuum bottoms, and DC of the deasphalter bottoms.

3) Visbreaking of the vacuum bottoms.

In the column 3 of **Table 5** in bold the main products of DC are shown: gas, distillates and coke, and the other results correspond to the simulated distillation of distil-

Table 4. Quality of the products from the upgrading of reduced crude.

	Reduced crude (RC)	DMO	DAB	DC of DAB	DC of RC
Density @ 15˚C, g/cm^3	1.0086	0.9817	1.0608	0.9314	0.936
API	8.7		1.8	20.3	19.6
CCR, wt.%	11.2	4.7	26.3	2.99	3.6
Sulphur, wt.%	2.25	1.6	2.3	1.533	1.5
Ca, ppm	345	41.5	1541		
Ni, ppm	79	17.0	195.78		
V, ppm	93	14.2	253.25		
Na, ppm	69				
Ni + V, ppm		31.2	449.0		
Refractive Index		1.5269			
insolubles in $nC_{7,}$ wt.%	2.6		11.8		
insoluubles in $nC_{5,}$ wt.%	6.2		23		
Viscosity-1, cP	577 a 120˚C	92			
Viscosity-2, cP	79200 a 135˚C	270			
Basic N, wt.%	0.218	0.1	0.4	0.2	0.17
N Total, ppm	6387	3828		5414	5570
N. N, mg KOH/g	7.4				
Pour point, ˚C	42				
SARA analysis, wt%				DMO-Demetallized Oil	
S	18.5	34.9	DAB-Bottoms from		
A	54	51.1	deasphalting		
R	25.1	14	DC-Delayed Coking		
A	2.4		RC-Reduced crude		

lates from DC. Column 4 shows the synthetic crude from this scheme before hydrotreating and column 5 the same products after Hydrotreating. Columns 6 to 9 present data from the scheme of vacuum bottoms deasphalting and DC of deasphalter bottoms. Column 9 shows the synthetic crude from this scheme.

Column 10 presents the data corresponding to the Visbreaking of the vacuum bottoms and column 11 shows the synthetic crude regarding to this scheme.

The composition of all synthetic crude is given considering not only the products of the given scheme of processing, but also include the components of oil which do not fall in the transformations given.

4.3.1. Delayed Coking of the Vacuum Bottoms (Table 5)

Coke production in relation to vacuum bottoms is of 22.2 wt.% (column 3), which is a fairly low value for this type of feed. This is due to the low concentration of coke precursors. The insolubles in n-C_7 are completely soluble in cyclohexane [23]. The CCR in the vacuum bottoms is 17.9 wt.%, and the insolubles in n-C_7 are 4.6 wt.% (**Table 6**). The typical values of CCR in the vacuum bottoms are above 25 wt.% (for the Castilla crude oil they are 37 wt.%).

In the consolidated for crude oil, the coke production is only 10.1 wt.%, a value similar to the production of coke in the consolidated scheme of DC of reduced crude. In the synthetic crude the production of naphtha is 6.2 wt.% and the yield of middle distillates (Jet and Diesel) is increased from 9.7 wt.% to 16.8 wt.% (column 5). Hydrogen treatments applied to DC distillates do not significantly alter their composition (columns 4 and 5 of **Table 6**).

This is a scheme of high conversion where only vacuum bottoms are processed; thereby the size of the up-

Table 5. Vacuum bottoms upgrading alternatives.

1	2	3	4	5	6	7	8	9	10	11
		Delayed Coking (DC) of the vacuum bottoms			**Deasphalting of vacuum bottoms and DC of DAB**				**Visbreaking (VR) of the vacuum bottoms**	
Atmospheric Distillation	**Crude oil**	**DC**	**Synthetic crude**	**Synthetic crude + HDT**	**Deas-phalting**	**DAB**	**DC of DAB**	**Consolidated**	**VR**	**Synthetic Crude**
Gases		**9.9**	4.5	4.5			**9.5**	2.8	2.0	0.9
Naphtha		20.0	6.2	5.5			19.0	3.1	5.7	2.6
Jet	2.5	9.0	5.3	5.3	2.5		8.0	3.9	0.9	2.9
Diesel	7.2	12.0	10.9	11.5	7.2		13.0	9.3	3.7	8.9
AGO	9.9	12.0	13.6	13.9	9.9		11.0	11.7	4.7	12.1
Vacuum distillation										
LGO	12.2	13.0	16.2	16.8	12.2		14.0	14.5	3.5	13.8
MGO	12.9	14.0	17.2	17.5	12.9	2.0	13.0	15.0	12.2	18.4
HGO	10.0	20.0	16.2	15.0	10.0	10.0	14.0	12.3	15.7	17.1
Vacuum bottoms	**45.3**					88.0	8.0	1.3	49.7	22.5
DMO					**36.0**			16.3		
DAB					**64.0**					
DC distillates		**67.9**					**57.0**			
Coke		**22.2**	10.1	10.1			**33.5**	9.7	1.8	0.8
Total	**100**	**100**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

DC—Delayed Coking; DAB—Bottmos from Deasphalting; VR—Visbreaking; HDT—Hydrotreating.

grader is reduced with respect to the processing of reduced crude.

4.3.2. nC_4 Deasphalting of the Vacuum Bottoms and DC of the Bottoms from the Deasphalter (Table 5)

The DMO yield with respect to the vacuum bottoms is 36.0 wt.% and the yield of deasphalter bottoms is 64.0 wt.%. This low yield of DMO is an indicative of the high aromaticity of this type of vacuum bottoms, which is confirmed by the SARA analysis (**Table 6**), where the sum of aromatics + Resins + asphaltenes is 91.1 wt.%. This type of crude should not be processed in a low conversion scheme because the fuel oil production is quiet high. The deasphalter bottoms yield with respect to the crude oil is 29.0 wt.%, a very high value.

Within the DC of the DAB are produced 9.5 wt.% of gases, 57.0 wt.% of distillates and 33.5 wt.% of coke (**Table 5**, Column 8), and within the distillates 51.0 wt.% correspond to atmospheric distillates and 41.0 wt.% to the vacuum distillates.

In the synthetic crude produced in this scheme (column 9), is observed that this scheme produces very low quantity of residues, only 9.7 wt.%, but the DMO concentrates very high amount of metals (282 ppm, **Table 6**) and this is neither good for the FCC feedstock not for the Hydrocracking.

4.3.3. Visbreaking of the Vacuum Bottoms (Table 5)

The Visbreaking of the vacuum bottoms produces a semi-synthetic crude oil in which the concentration of the cut corresponding to the vacuum bottoms is significantly reduced. It changes from 45.3 wt.% in the original crude oil to 22.5 wt.% in the semi-synthetic crude oil. On the other hand, the gas oils are increased from 45.0 wt.% in the raw material to 61.3 wt.% in the semi-synthetic crude (columns 2 and 11). The yield of coke is normal for this type of process.

The Visbreaking bottoms in the **Table 6** correspond to liquid effluents from the Visbreaking process, excluding naphtha.

This scheme is an ideal arrangement for a low conver-

Table 6. Properties of the products from the vacuum bottoms upgrading.

	Vacuum Bottoms	DC of vacuum bottoms	DMO	DAB	Visbreaking bottoms	Vacuum bottoms from VBR
Density @ 15˚C, g/cm^3	1.0262	0.9227	1.0284	1.0314	1.0459	1.0745
API	6.3	21.8	6	5.6	3.7	0.1
CCR, wt.%	17.9	4	18.3	25.8	25.9	34.9
Sulphur, wt.%	1.73	1.64	2.0	2.1	2.1	2.1
Ca, ppm	2666.0		852.5	337	982	1128
Ni, ppm	130.7		124.7	111.7	153	212.7
V, ppm	167.3		157.8	158.6	200	242.8
Na, ppm	38.5		33.2	43.5	32	29.4
Ni + V, ppm	298		282	270	354	455
i-nC_7, wt.%	4.63			9.16	17.3	25.7
i-nC_5, wt%	11.27			21.43	20.9	32.3
Viscosity-1, cP	30800 a 100˚C		322000 @80˚C	4780 @120˚C		0
Viscosity-2, cP	4950 a 120˚C		30100 @100˚C	1880 @140˚C		225000
Básico N, wt.%	0.284	0.186	0.284	0.312	0.373	0.441
N Total, ppm	7451	6681				1.21
N.N, mg KOH/g	3.93				2.88	0.8
Pour point, ˚C					51	126
Flash point, ˚C					173	323
SARA analysis, wt.%						
S	8.9				15.1	5.3
A	55.2				45.3	45.3
R	21.4				22.7	30.0
A	14.5				12.4	19.4

DC—Delayed Coking; DMO—Demetallized oil; VBR—Visbreaking.

sion refinery.

5. Cost of Technologies for Evaluated Schemes

The calculations were performed with the values presented in **Table 7** and on the basis of 50.000 BOPD.

In the **Table 8** are given the values of the different technological alternatives for the processing 50 KBOPD of crude Jazmín. The lower cost alternative is the Visbreaking of the Vacuum, bottoms and Hydrotreating of the distillates obtained from the VBR, followed by the alternatives of Visbreaking of the crude and DC of the DAB.

6. Conclusions

1) Jazmin crude oil and its heavy components are subjected to thermal processes with excellent results due to the low concentration of coke promoters. Coke production in relation to vacuum bottoms is of 22.2 wt.%, which is a fairly low value for this type of feed. This is due to the low concentration of coke precursors. The insolubles in n-C_7 are completely soluble in cyclohexane.

2) The scheme corresponding to the visbreaking of the crude oil and the DC of the vacuum bottoms from the visbreaking is perhaps the most attractive for its application because it has low capital cost and solves from the beginning the problem of crude acidity.

3) The best scheme to use depends on the needs of each refinery and its installed facilities.

4) Of the studied schemes, the less expensive because of the used technology is the Visbreaking of the vacuum bottoms, and Hydrotreating of the liquid effluents to stabilize all future products.

Table 7. Technology costs.

	Value of the technology	Taken value
	US$/Bl	US$/Bl
Atmospheric Distillation		1000
Atmospheric and Vacuum Distillation	750 - 2200	2000
Deasphalting	1850 - 8000	4000
Delayed Coking	5800 - 12,000	8000
Hidrotreating	3000 - 3500	3000
Visbreaking	1800 - 3500	3000
Crude for the process, bl/day		50,000

Table 8. Investment cost of the proposed schemes.

	Economic impact of the studied upgrading alternatives of the Jazmin crude	MMUS$
1	Visbreaking (VR) of the vacuum bottoms and HDT of the distillates from VR	236
2	Visbreaking of the crude and Delayed Coking of the Visbreaked vacuum bottoms	275
3	Deasphalting of the crude 199˚C+ and DC of the bottoms obtained in the deasphalting.	319
4	DC of the Vacuum bottoms and HDT of DC distillates	327
5	n-C4 Deasphalting of the vacuum bottoms; DC of the DAB, and HDT of the distillates from DC	331
6	n-C4 Deasphalting of the reduced crude and DC of the Deasphalted bottoms	334
7	Delayed Coking of reduced crude	478
8	Deasphalting of crude 199˚C+ and DC of its DMO	608

5) Thermal upgrading schemes not only increase distillates yield and reject carbon, but also reduce the acidity of the products.

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