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- (71) **Applicant:** SASOL TECHNOLOGY (PTY) LTD
[ZA/ZA]; 1 Sturdee Avenue, Rosebank, 2196 Johannes-
burg (ZA).
- (72) **Inventors:** SWART, Andre; 20411 Spring Rose Drive,
Katy, Texas 77450 (US). KRETT, Jerry, Joseph; 7835
Springbank Way SW, Calgary, AB T3H 4J7 (CA). ES-
TERHUYSE, Nico; 3 Goedehoop Street, Briza, 7130
Somerset West (ZA).
- (74) **Agents:** LUTEREK, Janusz, F. et al.; Hahn & Hahn, 222
Richard Street, Hatfield, Pretoria 0083 (ZA).
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(54) **Title:** FISCHER-TROPSCH DERIVED HEAVY HYDROCARBON DILUENT

(57) **Abstract:** The invention provides a process for making a heavy hydrocarbon feed pipeline transportable, said process including blending the heavy hydrocarbon feed with a diluent including a hydrocarbon stream having at least 0.5% by mass of a C₄ or lighter hydrocarbon component, said diluent having less than 2% by volume aromatics, wherein the viscosity of the heavy hydrocarbon feed and diluent blend is below 500cSt at 7.5°C which is within pipeline transportable limits.



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FISCHER-TROPSCH DERIVED HEAVY HYDROCARBON DILUENT**FIELD OF THE INVENTION**

The invention relates to a process in which hydrocarbons produced by a Fischer Tropsch process are blended with heavier hydrocarbon streams in order to facilitate transportation of the heavier hydrocarbon streams, more specifically the Fischer Tropsch derived hydrocarbons of this invention is suitable as a diluent for heavy hydrocarbons.

BACKGROUND OF THE INVENTION

Certain heavy hydrocarbon deposits, such as the oil sands found in Western Canada, require significant refining to render them suitable for use as fuel or as another conventional crude-derived product. Oil sands are essentially deposits of heavy, highly viscous hydrocarbons with a very high resin and asphaltene content. The chemical nature of the heavy hydrocarbons renders them difficult to extract, transport and upgrade. This is exacerbated by the fact that they are typically located in regions that are very remote from the refineries that can upgrade them. If they are to be transported effectively by pipeline to an upgrading facility, their viscosity must be effectively reduced by either blending with an externally sourced, lower viscosity liquid (diluent); or upgrading a portion of the heavy hydrocarbon itself *in situ* to produce a suitable carrier stream.

Ideally, diluents are used to reduce the viscosity of the heavy hydrocarbon stream (eg. bitumen) to the point where the diluted heavy hydrocarbon can be injected into and transported in a standard (non-heated) pipeline. The biggest risk when employing a diluent is that any chemical incompatibility between the bitumen and diluent species can lead to the precipitation of asphaltene solids, which could have a significant operational impact on pipeline operation. This precipitation occurs when the asphaltene molecules, which occur as a colloidal suspension, become destabilised then flocculate and agglomerate.

Hence the choice of suitable diluent chemistry requires that sufficient diluent be accommodated to reduce the viscosity to below the practical pipeline limits (for example less than 350 cSt at 7.5 °C) whilst still retaining the stability of the asphaltene colloids that comprise much of the heavy hydrocarbon stream.

US 7,491,314 discloses the partial upgrading of a portion of the heavy hydrocarbon stream itself. This upgraded stream is used as an *in situ* diluent stream to make the heavy hydrocarbon pipeline-transportable and also generate some power/heat for the extraction process.

US 6,531,516 discloses the use of GTL-derived naphtha as a suitable diluent for heavy hydrocarbons as part of entire integrated bitumen and gas conversion process. It clearly teaches that the diluent includes hydrocarbons in the range beginning from C₅ up to as high as 213 – 232 °C.

US 6, 277, 269 teaches the production of pipelineable bitumen by an improvement in modifying the density and viscosity so as to meet pipeline specification, the improvement including subjecting a heavy hydrocarbon to hydroconversion under conditions to modify the viscosity and adding a diluent to the modified hydrocarbon.

SUMMARY OF THE INVENTION

According to one aspect of the invention there is provided a process for making a heavy hydrocarbon feed pipeline transportable, said process including blending the heavy hydrocarbon feed with a diluent including a hydrocarbon having at least 0.5% by mass of a C₄ or lighter hydrocarbon component, said diluent having less than 2% by volume aromatics, wherein the viscosity of the heavy hydrocarbon feed and diluent blend is below 500cSt at 7.5°C which is within pipeline transportable limits.

The hydrocarbon of the diluent may be Fischer Tropsch (FT) derived.

The diluent may be a blend of the Fischer Tropsch (FT) derived hydrocarbon and at least 0.5% by mass of the C₄ or lighter hydrocarbon component.

The diluent may have an aromatics content less than 1% by volume.

The diluent may have an aromatics content less than 0.1% by volume.

The FT-derived hydrocarbon may be a naphtha.

The FT-derived hydrocarbon may be a diesel.

The diluent may have at least 2% by mass of a C₄ or lighter hydrocarbon component.

The diluent may contain no more than 5% by mass of a C₄ or lighter hydrocarbon component.

The C₄ or lighter hydrocarbon component may be derived from a FT process.

According to a second aspect of the invention there is provided a FT-derived hydrocarbon suitable for use as a heavy hydrocarbon diluent that includes at least 0.5% by mass of a C₄ or lighter hydrocarbon component to produce a blend having a viscosity of less than 500 cSt at 7.5 °C.

- 5 The FT-derived hydrocarbon includes no more than 5% by mass of a C₄ or lighter hydrocarbon component.

Typically to be pipeline transportable a heavy hydrocarbon feed should have a viscosity of below 500cSt at 7.5 °C, generally below 350 cSt at 7.5 °C.

10 DETAILED DESCRIPTION OF THE INVENTION

The inventors have found that, contrary to what was expected, it is possible to blend up to 5% of a light hydrocarbon fraction (C₄ and lighter) with FT-derived naphtha; and still obtain a product that is highly suitable for use as a heavy hydrocarbon diluent. This finding is surprising because the expectation was that incorporating significant levels of light hydrocarbons (C₄ and less) without the significant presence of aromatic species (normally required at, for example, levels of at least 2% by volume) would result in substantial asphaltene incompatibility; caused by the considerable molecule size mismatch between these very light hydrocarbons and the asphaltene molecules.

This finding that an FT-derived diluent for bitumen can be produced by blending in up to 5 % by mass of butane (or a similar light hydrocarbon component that is predominantly equal to or less than C₄) with the naphtha or diesel cut, without causing incompatibility has significant commercial implications. It enables the use of a broader spectrum of the lighter hydrocarbons produced by the FT process; and also enables a more effective reduction in the density of the diluent, in order to improve the ratio on blending into the heavy hydrocarbon stream.

As defined in US 7 491 314, a pipeline-transportable hydrocarbon feed is able to be transported by pipeline over considerable distances (usually over 500km, but even in excess of 1000km). This should occur with reasonable energy expenditure in terms of pumping and infrastructure requirements. In the context of this invention, a current upper viscosity threshold for pipeline injection would be approximately 350 cSt at 7.5°C. It should be noted that this threshold could shift depending on the exact technology conditions involved for the pipeline transportation system.

Fischer Tropsch (FT) process

FT synthesis can be used at two temperature ranges: (i) the so-called Low Temperature Fischer-Tropsch (LTFT) process, typically below 300°C, and (ii) the so-called High Temperature Fischer-Tropsch (HTFT) process, typically above 300°C.

The FT process is used industrially to convert synthesis gas, derived from coal, natural gas, biomass or heavy oil streams, into hydrocarbons ranging from methane to species with molecular masses above 1400. While the main products of the FT process are linear paraffinic materials; other species such as branched paraffins, olefins and oxygenated components form part of the product slate. The exact product slate depends on reactor configuration, operating conditions and the catalyst that is employed, as is evident from e. g. *Catal. Rev.-Sci. Eng.*, **23** (1 & 2), 265-278 (1981).

Preferred reactors for the production of heavier hydrocarbons are slurry bed or tubular fixed bed reactors, while operating conditions are preferably in the range of 160-280° C, in some cases 210-260°C; and 18-50 Bar, in some cases 20-30 bar. Preferred active metals in the catalyst comprise iron, ruthenium or cobalt. While each catalyst will give its own unique product slate; in all cases, the product slate contains some waxy, highly paraffinic material which needs to be further upgraded into usable products.

The FT products can be converted into a range of products, such as naphtha, middle distillates, etc. Such conversion usually consists of a range of processes such as hydrocracking, hydrotreatment and distillation.

Heavy hydrocarbon feed

Heavy hydrocarbon feeds suitable for use in the practise of the invention are those that contain a substantial portion with a boiling point greater than about 525°C. Of particular interest are the heavy hydrocarbon oils that can be extracted from sources such as the Athabasca and Cold Lake oil sands. Such heavy hydrocarbons will be extremely viscous, typically having a viscosity at 80°C in excess of 500 cSt.

Table 1, following, gives some basic properties of representative heavy hydrocarbon, Mackay River bitumen.

5 TABLE 1

Mackay River Bitumen		
Element	Result	Units
DENSITY 15.6° C	1.0108	g/ml
DENSITY 15°C	1008.3	Kg/m ³
WATER CONTENT	0.040	wt%
TOTAL SULPHUR CONTENT	4.74	wt%
VISCOSITY @ 80°C	592.8	cSt
VISCOSITY @ 100°C	205.8	cSt
MICROCARBON RESIDUE	13.0944	wt%
TOTAL ACID NUMBER	2.823	mg KOH/g
SARA ANALYSIS	--	--
SATURATES	15.5	wt%
AROMATICS	53.34	wt%
RESINS	12.8	wt%
ASPHALTENES (PENTANE INSOLUBLES)	18.359	wt%
WIEHE SOLUBILITY NUMBER	95.58	n/a
WIEHE INSOLUBILITY NUMBER	31.65	n/a
P-VALUE	3.02	n/a
CARBON CONTENT	83.9	wt%
HYDROGEN CONTENT	10.65	wt%
NITROGEN CONTENT	0.4	wt%

FT-derived hydrocarbon stream

FT-derived hydrocarbon streams that are suitable for use as a diluent in the practise of this invention may be selected from:

- naphtha which includes hydrocarbons boiling in the range from C₅ up to approximately 230 °C; where a light naphtha typically boiling in the range from C₅ up to about 160°C and a heavy naphtha typically boiling in the range from 130 °C up to about 230 °C would be suitable;
- a middle distillate fraction which includes hydrocarbons boiling in the range from 120 °C up to approximately 370 °C;
- blends of suitable hydrocarbons boiling in the naphtha and middle distillate ranges.

The naphtha has the lowest viscosity and is hence typically preferred for use to dilute the bitumen for pipeline transportation. In the case of this invention, Gas-to-Liquids (GTL) FT processes are typically preferred because of the plentiful supply of natural gas that is usually found in or near tar sand formations.

Table 2, following, gives typical characteristics of such a suitable GTL FT-derived naphtha.

TABLE 2

PARAMETER	METHOD	RESULT	UNITS	SPECS	
				Min	Max
Density @ 15°C	ASTM D4062	678.8	kg/m ³	600	775
Viscosity @ 7.5°C	ASTM D445	0.63	cSt	—	2.0
Sulfur, total	ASTM D5453	0.0001	wt%	—	0.5
Olefins, total	ASTM D6729 (250°C cut)	0.19	wt%	—	<1
Reid Vapour Pressure	ASTM D323	49	kPa	—	103
BS&W	ASTM D95	0.003	mass%	—	0.5
Organic Chlorides	ASTM D4929 (204°C cut)	<1	wppm	—	<1
Aromatics, total BTEX	ASTM D6729 (250°C cut)	0.040	vol%	2.0	—
Mercaptans, volatile (C1, C2, C3)	ASTM D5623	<0.5	wppm	—	175
H ₂ S (in liquid phase)	ASTM D5623	<0.5	wppm	—	20
Benzene	ASTM D6729 (250°C cut)	<0.01	vol%	—	1.6
Mercury	UOP 938 (CVAA)	<10	wppb	—	10
Oxygenates	ASTM D6729 (250°C cut)	<100	wppm	—	100
Filterable Solids	ASTM D4807 (procedure C)	3.0	mg/L	—	200
Phosphorous, volatile	ASTM D5708	<0.5	ppm	—	—
Selenium	ASTM D5807A (ICPMS)	1	wppb	—	—
Pour Point	ASTM D97	<-65	°C	—	—
Salt Content	ASTM D3230	<0.1	ptb	—	—
SimDist	ASTM D2887	See Attached	vol%	—	—
Remarks RVP performed by ASTM D323					

5 **Table 3** gives further characteristics of various types of suitable GTL naphtha that may be derived from an FT process. For example:

- straight run naphtha (designated SR) which is naphtha derived directly from the FT process product by fractionation
- hydrotreated straight run (designated HSR) naphtha which is SR naphtha that has been hydrotreated to reduce the content of olefinic and oxygenated compounds
- hydrocracked (designated HX) naphtha which is naphtha that is derived by cracking longer chain hydrocarbons derived from the FT process product down to naphtha-range material using hydroconversion, which is then followed by fractionation
- a combination HX and HT SR (designated GTL) naphtha

TABLE 3

	Synthetic FT Naphthas				Commercial SA Diesel	Notes
	SR	HT SR	HX	LTFT		
ASTM D86						
IBP, °C	58	60	49	54	182	
T10, °C	94	83	79	81	223	
T50, °C	118	101	101	101	292	
T90, °C	141	120	120	120	358	
FBP, °C	159	133	131	131	382	
Density, kg/L (20°C)	0.7101	0.6825	0.6877	0.6852	0.8483	
Cetane Number	n/a	42,7	30,0	39,6	50,0	
Heat of Combustion, HHV, kJ/kg	45 625	48 075	46 725	46 725	45 520	note 2
Acid Number, mg KOH/g	0.361	0.001	0.011	0.006	0.040	
Total sulphur, mg/L	<1	<1	<1	<1	4 242	
Composition, % wt						
n-paraffins	53,2	90,1	28,6	59,0	n/a	
Iso-paraffins	1,2	8,3	66,7	38,2	n/a	
Naphthenics	-	-	-	-	n/a	
Aromatics	-	0,1	0,5	0,3	n/a	
olefins	35,0	1,5	4,2	2,5	n/a	
alcohols	10,7	-	-	-	n/a	
Cloud Point, °C	-51	-54	-35	-33	4	
Flash Point, °C	-9	-18	-21	-20	57	note 3
Viscosity	n/a	n/a	n/a	0,50	3,97	

Notes: 1. These fuels contain no additives; 2. API Procedure 14A1.3; 3. Correlated (ref.: HP Sep 1987 p. 81)

Typically the concentration of C₄ and lighter hydrocarbons in GTL naphtha is extremely low, unless special storage precautions are taken to reduce loss by evaporation. This is governed by the fact that the boiling point of paraffinic hydrocarbons lighter than C₅ is significantly less than room temperature, with C₄ paraffins having a normal boiling point at -1°C and C₅ paraffins boiling at approximately 36°C. Hence the naphtha fraction of interest in this invention will typically have a C₄ or lighter hydrocarbon content less than 1.0 % by mass or even more typically less than 0.5 % by mass.

Fraction that is C₄ and lighter

Light hydrocarbon streams that are suitable for use in the practise of this invention will be predominantly C₄ or lighter; and may be a single hydrocarbon such as normal butane; or may be a blend of suitable hydrocarbons.

The C₄ or lighter hydrocarbon stream may be selected from a crude-derived source; an FT-derived source; or a combination thereof. It is further postulated that the increased olefin content of an FT-derived source could yield beneficial effects in terms of asphaltene stability/solubility. For example,

C₃₋₄ olefins may comprise between 1 and 5 mass% of the total FT synthesis product (excluding inert gases and water gas shift product) and can more typically be between 2.5 and 4 mass % ; whilst C₃₋₄ paraffins will typically comprise less than this (between 0.5 and 2 mass %) and can more typically be between 1.5 and 2 % by mass . The mass ratio of olefins to paraffins in the C₃₋₄ range will hence typically be between 3:1 and 1.5:1; and can more preferably be approximately 2:1.

An example of a suitable composition for practising this invention would be field-grade or mixed butane, defined as a product consisting chiefly of normal butane and isobutane, such as that produced at a gas processing plant. Such a mixed butane typically consists of a mixture of isobutane, normal butane (with some propane, and small amounts of isopentane and normal pentane being present). Characteristically such a mixed butane consists of at least 60% by volume n-butane and approximately 20 % by volume of isobutane, such that the overall combined butane content is at least 80% by volume. Field butane compositions typically result in increased volatility when compared with pure normal butane because of the presence of propane and other lighter hydrocarbons.

The light hydrocarbon stream of this invention may be an FT-derived hydrocarbon; which would hence enable the effective utilisation of more of the FT-derived products. In the case of an FT-derived light hydrocarbon fraction; a further method of introducing a significant quantity of C₄ or lighter hydrocarbon into the naphtha stream would be to choose the initial lower FT naphtha cut point to be lighter than is the case conventionally. This would allow for a suitable C₄ and lighter fraction without having to blend it in subsequently. It is noted that such a stream would require special handling/storage conditions in order to preserve the C₄ and lighter fraction for use in blending.

Heavy hydrocarbon/diluent stability

FT-derived hydrocarbon streams typically have aromatic contents much lower than 2% by volume. According to the Enbridge CRW pool diluent specifications (which are extensively used for determining diluent fit-for-purpose); if a proposed diluent has an aromatics content less than 2 % by volume then compatibility testing must be carried out to demonstrate suitability.

Compatibility testing is carried out according to the well-accepted Wiehe test method as published by Wiehe in *Energy Fuels*, 2000, **14**(1), pp 56-59. According to this method, the Wiehe solubility

factors for non-solvent oils (SNSO) are determined by titrating a reference hydrocarbon with asphaltene present with the proposed diluent non-solvent hydrocarbon. Non-solvent hydrocarbons will not contain any asphaltene (such as the diluents proposed in this application). The reference heavy hydrocarbon used for this characterisation is an Athabasca heavy hydrocarbon. The SNSO value gives a very clear indication of the compatibility of the proposed diluent-heavy hydrocarbon system.

EXAMPLE

A blend of GTL-derived naphtha with a representative "field" butane sample at 5% by mass was produced. The compatibility of the pure GTL naphtha and the GTL naphtha/butane blend were then determined in accordance with the Wiehe test method. A standard diluent hydrocarbon reference sample was also assessed according to the test methodology. The SNSO results of this characterisation are shown in Tables 4 to 6.

TABLE 4: Results for GTL Naphtha

COMPATIBILITY TEST			OTHER TESTS		
Element	Result	Units	Element	Result	Units
DENSITY	0.6787	g/ml	DENSITY 15.6 C	0.6787	g/ml
TEST (REF) OIL	QC ATHA		TAN NUMBER	0.01	mg KOH/g
TE OF TEST OIL	19	% Tol	NITROGEN	0.5	mg/l
DENSITY OF TO	1.0074	g/ml			
VH OF TEST OIL	10.1	ml C7/5 ml			
VNSO	9.1	ml NSO/5ml			
SNSO	-3.49				

TABLE 5: Results for GTL naphtha blended 5% volume field butane

COMPATIBILITY TEST		
Element	Result	Units
DENSITY	0.6737	g/ml
TEST (REF) OIL	QC ATHA	
TE OF TEST OIL	19	% Tol
DENSITY OF TO	1.0074	g/ml
VH OF TEST OIL	10.1	ml C7/5 ml
VNSO	9.1	ml NSO/5ml
SNSO	-3.49	

OTHER TESTS		
Element	Result	Units
DENSITY 15.6 C	0.6737	g/ml
TAN NUMBER	<0.001	mg KOH/g
NITROGEN	0.4	mg/l

TABLE 6: Results for reference diluent sample

COMPATIBILITY TEST		
Element	Result	Units
DENSITY	0.695	g/ml
TEST (REF) OIL	QC ATHA	
TE OF TEST OIL	19	% Tol
DENSITY OF TO	1.0074	g/ml
VH OF TEST OIL	10.1	ml C7/5 ml
VNSO	10.9	ml NSO/5ml
SNSO	2.33	

OTHER TESTS		
Element	Result	Units
DENSITY-15.6 C	0.695	g/ml
TAN NUMBER	41.4	mg/L
NITROGEN	0.03	mg/KOH g

According to the Wiehe test methodology, the results of this analysis indicate that the GTL naphtha blend with field butane had the same compatibility with heavy hydrocarbons as did straight GTL naphtha. An SNSO value of -3.49 for both samples compares favourably with the reference diluent sample, indicating slightly lower compatibility than is the case for the reference diluent (which has an SNSO value of 2.33).

According to the Wiehe Oil Solubility Model, a theoretical assessment was then made of the blends with a MacKay bitumen at which compatibility limits will be reached, using the measured solubility data reported above. Because the GTL naphtha and its blend with butane had the same solubility number (SNSO), only one theoretical blend calculation was completed. The compatibility limit for the GTL naphtha and GTL naphtha/butane when blended with the bitumen were hence determined to be 64.5% naphtha, according to the results shown in **Table 7**. (The resulting P-values are reported

– where P-values less than 1.0 are considered to be unstable.) For comparison purposes, the reference diluent sample has a compatibility limit of 68%.

In practise, the viscosity of the diluted bitumen is usually kept close to the upper pipeline injection limit of 350 cSt at 7.5°C, such that the typical lower blending threshold for the GTL naphtha/butane blend in this case would be approximately 31%.

GTL naphtha blended with 5% butane is hence determined to be compatible with bitumen in a blend of up to 64.5%; where levels of just 31% are required blended with MacKay bitumen in order to achieve viscosities that are required for transportation in a pipeline.

Table 7 : Solubility Factors - GTL Naphtha & GTL naphtha/C4 blend with Mackay bitumen

%-MacKay vol.	%-GTL vol.	SBN Mix	P-Value
100.000	0.000	95.580	3.020
95.000	5.000	90.627	2.863
90.000	10.000	85.673	2.707
85.000	15.000	80.720	2.550
80.000	20.000	75.766	2.394
75.000	25.000	70.813	2.237
70.000	30.000	65.859	2.081
65.000	35.000	60.906	1.924
60.000	40.000	55.952	1.768
55.000	45.000	50.999	1.611
50.000	50.000	46.045	1.455
45.000	55.000	41.092	1.298
40.000	60.000	36.138	1.142
35.000	65.000	31.185	0.985
30.000	70.000	26.231	0.829
25.000	75.000	21.278	0.672
20.000	80.000	16.324	0.516
15.000	85.000	11.371	0.359
10.000	90.000	6.417	0.203
5.000	95.000	1.464	0.046
0.000	100.000	-3.490	-0.110

REFERENCES

Oil Compatibility Model; as described in: Wiehe, *Energy Fuels*, 2000, **14**(1), pp 56-59.

CLAIMS:

1. A process for making a heavy hydrocarbon feed pipeline transportable, said process including blending the heavy hydrocarbon feed with a diluent, said diluent including;
 - a. a hydrocarbon having at least 0.5% by mass of a C₄ or lighter hydrocarbon component;
 - b. less than 2 vol% aromatics,wherein the viscosity of the heavy hydrocarbon feed and diluent blend is below 500cSt at 7.5 °C.
2. A process as claimed in claim 1, wherein the hydrocarbon of the diluent is Fischer Tropsch (FT) derived.
3. A process as claimed in claim 1, wherein the diluent includes less than 1 vol% aromatics.
4. A process as claimed in any one of the preceding claims, wherein the diluent includes less than 0.1 vol% aromatics.
5. A process as claimed in claim 2, wherein the FT-derived hydrocarbon is selected from a naphtha or diesel or a combination of the two.
6. A process as claimed in claim 1, wherein the diluent includes at least 2 mass % of a C₄ or lighter hydrocarbon component.
7. A process as claimed in any one of the preceding claims, wherein the diluent includes 5 mass% or less of a C₄ or lighter hydrocarbon component.
8. A process as claimed in any one of the preceding claims, wherein the C₄ or lighter hydrocarbon component is FT derived.
9. A process as claimed in any one of the preceding claims, wherein the viscosity of the heavy hydrocarbon feed is reduced below 350 cSt at 7.5 °C
10. Use of a FT-derived hydrocarbon including at least 0.5 mass% of a C₄ or lighter hydrocarbon component as a heavy hydrocarbon diluent to produce a blend having a viscosity of less than 500 cSt at 7.5 °C.

11. Use of a the FT-derived hydrocarbon as claimed in claim 10, which stream includes less than 5 mass% of a C₄ or lighter hydrocarbon component.

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
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According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F17D C10G E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 531 516 B2 (DAVIS STEPHEN MARK [US] ET AL) 11 March 2003 (2003-03-11) cited in the application column 2, line 24 - column 5, line 29 -----	1-11
A	RAFAEL MARTÍNEZ-PALOU ET AL: "Transportation of heavy and extra-heavy crude oil by pipeline: A review", JOURNAL OF PETROLEUM SCIENCE AND ENGINEERING, vol. 75, no. 3-4, 1 January 2011 (2011-01-01), pages 274-282, XP055083811, ISSN: 0920-4105, DOI: 10.1016/j.petrol.2010.11.020 the whole document ----- -/--	1-11



Further documents are listed in the continuation of Box C.



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Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

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Iyer-Baldew, A

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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