MATHEMATICAL MODEL TO PREDICT THE TANKERS SAFE LOAD WITH VACUUM GASOIL

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Abstract.
A great number of Vacuum Gasoil transshipments data obtained in the last 5 years from more than 23 major transshipment hubs have been investigated in this work in order to obtain a general analysis of its possible contaminants in the Midstream Sector. The data correlated in model were gathered from samples taken before, during and after the transshipment between wither Terminal/Vessel, Vessel/Vessel and Vessel/Terminal as per ASTM D4057. The analysis was thereafter performed in laboratories of First-Class Independent Inspector Laboratory and Terminals/Refineries laboratories. Correlations were derived which show that the vacuum gasoil quality is highly influenced by the Onboard Quantity (OBQ) present on board of the vessel before loading, far more than shown in the International Standard Guidelines in force at present time. It was found that implementing a blending program library along with a statistical data base and existing general guidelines drawn both from International Standards in Force and guidelines proposed by the author, generated a mathematical and logical model that delivers the maximum content of Fuel Oil in a given tank, over which we can safely load the Vacuum Gasoil, excluding the possible damage by contamination in 99% of the cases. The same model was run on the existing data from previous operations selected by a randomizer program, respecting the request to have a prediction reliability of 99%. In addition, this model can further indicate the level of damage suffered already by the Vacuum Gasoil, which was already contaminated with Fuel Oil, for which can be of high value in case of an investigation or pending Claim towards recovering the damage.

Key words: OBQ, vacuum Gasoil, fuel oil, contamination, asphaltenes

Introduction

Over the recent years, there has been an increase in the qualitative incidents in the Midstream Sector of the Oil and Gas Industry. The challenges arises due to the ever-fluctuating price of crude and petroleum products in all over the world.

The marketers are always looking for the best price on the market, price which usually comes with a hidden aspect. And since most of the quantitative

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losses are being limited and dissipated due to more and more efficient quantification solutions available, the speculation on the price tends to lean towards a qualitative direction. The quality claims in midstream sector, with preponderance in the Marine Shipping Industry, has always had its downsides, before due to the lack of technology to allow a very accurate and representative sampling and analysis of the cargo, and thereafter due to the limitations imposed by performing such verifications on board of tankers. Even if the industry has come a long way and succeeded to establish a minimum standard requirement [1] in order to increase the representativity of the results obtained, due to the numerous different particularities of each operation there are still many gaps to cover when it comes to perform the best qualitative due diligence.

One of the factors that tend to not be given a response nowadays is the On-Board Quantity of a tanker or shore tank (also referred as OBQ [2]), which represents, without a doubt, a risk of contamination for the nominated cargo subjected to be loaded. And since the tank cleaning procedures [3] are lengthy, costly, bunker consumable, water consumable and generate slops, all marketers tend to avoid it, taking a risk that is often proven unsubstantiated* (*to be noted that every marketer has a different approach for each particular case and that the above is a subjective opinion based on the authors experience in the field, trend observed and specific only for the referrals subject to this article*). If in the past the inspections performed in a tank [4] were much more thorough and not so time depending, nowadays the pre-transfer tanks condition inspections are very limited (due to inert gas conditions of the tanks), also due to a very limited time window for loading and delivery of the product.

One of the many products that has suffered due to this market trend is the Vacuum Gas Oil. Vacuum Gas Oil can be considered an intermediary petroleum product in the refining industry. It is a very quality restrictive product due to the refining processes that it is involved in, processes that are very sensitive to the variations of several crucial parameters like metals, water and asphaltenes, all of which can be found in quite significant levels in fuel oil. Due to the unbalanced production of refineries, Vacuum Gas Oil has become in the recent market both product and feedstock. However, since most refineries are not direct connected through a system of pipelines, and due to the high limitative variations of the qualitative demands over the offer, transportation via sea ways was and is still considered the most viable. Transportation of the Vacuum Gas Oil from the place of its production towards its destination (usually another refinery or in some cases a temporary storage) has its downsides due to the highly risk of contamination. Considering that the Vacuum Gas Oil is not one of the most common traded petroleum product (in comparison with gasoline, gasoil, crude oil and Fuel Oil), there are not so many dedicated storage shore facilities or marine tankers dedicated exclusively for this product. For the marine tankers, this would imply most of the time very low-cost effective routes and increased demurrages, all money consuming risks that no one cares for or can afford to take. The response found by the industry in this sense was to appoint a Cargo Expeditor [5] which must assess the situation in all its variables and propose the most cost-effective solution to the parties involved. However, this solution is based on the experience of the cargo expeditors with other similar situations and its base knowledge, avoiding or excluding completely the most important part of the issue, which is the prevention part.

In this paper, we will study the behavior of loaded Vacuum Gas Oil on board of the vessels that carried previously Fuel Oil of different qualities, including in it the analysis of several possible cases for cargo tanks preparation and cleaning procedures. The results obtained will thereafter be interpreted into a model that tries to include more parameters and factors to offer a more reliable picture of the risk taken and to limit as much as possible the contamination of the commodity. Also, the model has the target to surpass all the existing industry standards like API/MPMS HM50 [4] or BP Tank Cleaning Guide [6], all in respect of loading VGO on top of Fuel Oil OBQ.

Experimental

In this Step, we have gathered and investigated data from 1,233 Vacuum Gasoil transshipments, relevant to more than 23 major transshipment hubs, throughout 5 years, in order to obtain a general analysis of contamination in the midstream sector. Locations and participation percentages in Vacuum Gasoil transshipments data are given with Fig.1. The data correlated in the model in respect of the Vacuum Gas Oil product studied, were gathered from samples taken before, during and after the transshipment between terminal/vessel, vessel/vessel and vessel/terminal. The analyses of Vacuum Gas Oil were performed in First-Class Independent Inspector Laboratories or Terminals/Refineries Laboratories using international approved standard method of analysis [7-14], relevant to the quality specification sold or bought. The data results gathered were filtered for non-representative cases where there were indications of non-homogeneity (especially in on-board blending cases), where sampling on board was considered as non-representative and the analysis results were non-comparable with shore results in the critical parameters [15] (i.e: density, viscosity, flash point, pour point, water by distillation, sulphur), where laboratory analysis were not performed using standard industry test procedures, as specified in the ASTM or where there were suspicious or proven cases of fraud for quantitative or qualitative procedures used.

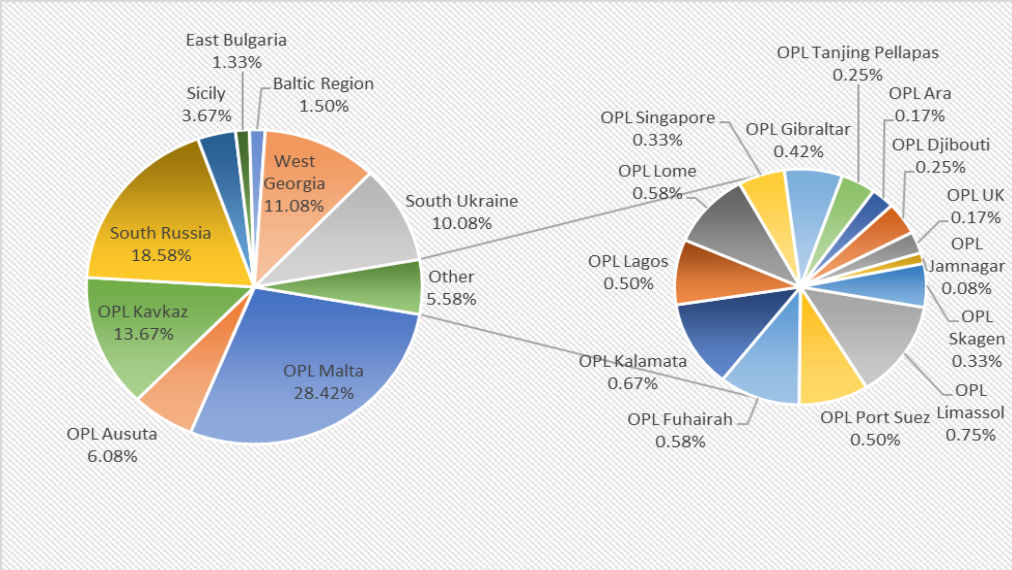

Fig. 1. Locations and participation percentages in Vacuum Gasoil transshipments data

In addition, in respect of the selected cases of study, we collected data regarding the size of the vessel, cargo tanks geometry, capacity of vessel's interior and deck cargo lines, last cargo or cargoes carried with their relevant quality, information about remaining on board after the last discharge of the respective vessel and inspection data on the On Board Quantity (OBQ) determined before loading of the Vacuum Gasoil, especially where measurable quantities were determined.

The sale specification of VGO from different regions were then used in order depict the critical limit values that have the greatest impact in risk of contamination when loading it on top of Fuel Oil OBQ. Putting the data available side to side it was almost immediately notable that the VGO most sensitive quality parameter in this type of situation was the asphaltenes content. Figure 2 and Figure 3 are presenting the variation of asphaltenes content of the VGO before loading (as analyzed from the samples drawn before loading ex. Shore Tank/s [15]) and the results obtained after loading (as analyzed from the samples drawn after loading ex. Vessel's Cargo Tanks [16]).

Vacuum Gasoil quality available on market. Even though the present market offers a wide range of VGO with respect to its quality, it is trended in the sector of Petroleum Trading to pin a certain quality frame to a region. For example, we can see from Table 1 that the content of asphaltene in the VGO lifted from South Russian Region tends to be lower than the ones available in the Mediterranean area. However, even with the wide array of quality fingerprints available to differentiate each VGO one from another, there does not seem to be a dependence between the asphaltenes content and the other parameters.

Typical selling specification of vacuum gasoil. Of course, Trading of Petroleum Products is a two way street because more of than usual, the deals are not back to back on quality clause. That leads almost every time to a different quality selling specification compared to the quality purchase one. In Table 2 we can see few selected cases with the limits imposed by several buyers of the VGO. Most of the receivers will factor their quality clauses and requirements in line with the scope of use of the VGO. Furthermore, receivers are also amending their quality requirements in line with a discounted price, dependent with the demand of the material [16-17].

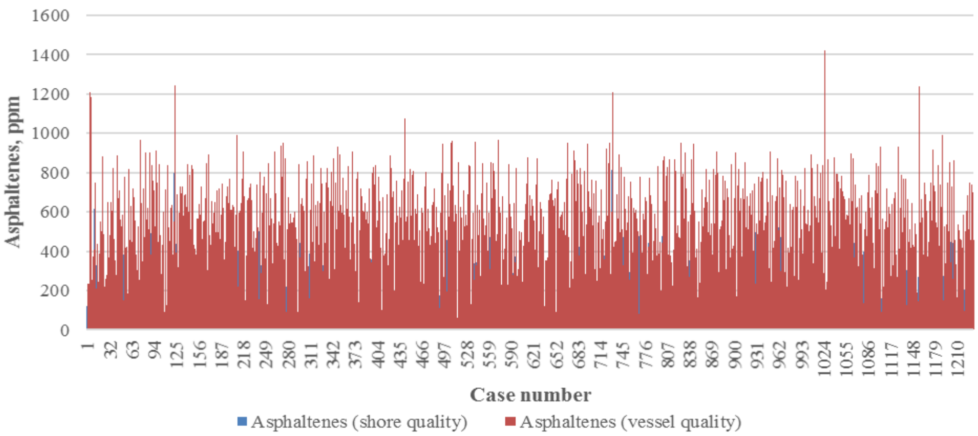

Fig. 2. Shore/Ship of total asphaltenes content in vacuum gasoil transshipments (1232 cases)

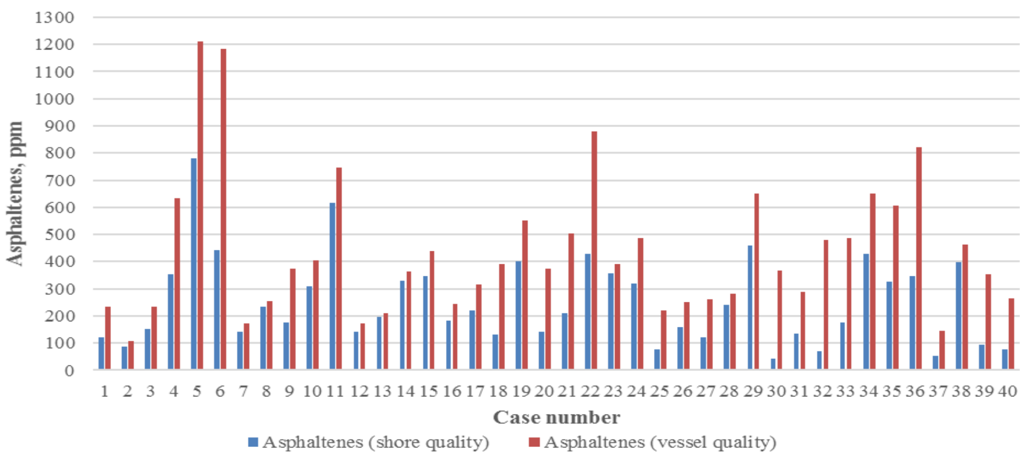

Fig. 3. Shore/Ship detail respect to total asphaltenes content in vacuum gasoil transshipments for 40 cases from Fig. 2

Vacuum Gas Oil is often very restrictive on quality requirements when bought, especially on parameters like asphaltenes, carbon residue (CCR), metals and water content. For our selected cases, Selling Specification Qualities limit the asphaltenes content to an average of 500 ppm.

Table 1

Examples of Vacuum Gasoil quality available on market

№	Parameter	Units	East Bulgaria	East Turkey	South Greece	South France	West Georgia	South Spain	West Spain	South Russia
1	Density at 15°C	g/l	924.5	918.7	895.5	912.0	914.6	932.6	886.2	911.2
2	Kinematic Viscosity at 50°C	cSt	16.26		14.54	59.17	47.05	36.00		43.96
3	Sulphur	% mass	0.48	0.26	1.6	0.98	0.268	1.26	0.448	0.871
4	Pour Point	°C	21	18	33	45	6		48	33
5	Flash Point	°C		130	93.5	184	146	>120	175	185
6	Asphaltenes	ppm	780	250	70	469	760	1042	195	294
7	Organic Chlorides	ppm	ns	ns	<2	ns	1	ns	<1	0.3
8	Carbon Residue	% mass	0.22	0.15	0.1	0.35	0.4	ns	0.12	0.27
9	Bromine Number at 360°C cut	mgBr/100g	ns	ns	3	2.6	2.8	ns	1.8	2.1
10	Nickel	mg/kg	0.2	0.3	0.1	0.1	1.1	ns	2	0.1
11	Vanadium	mg/kg	0.4	0.27	0.5	0.8	1.1	ns	<1	0.5
12	Sodium	mg/kg	ns	5.46	0.1	0.1	1	0.2	0.2	0.3
13	Copper	mg/kg	<1	<1	ns	<0.2	0.2	ns	<1	<0.1
14	Iron	mg/kg	1.63	ns	0.1	0.1	2.3	ns	<1	0.4
15	Aluminum	mg/kg	ns	ns	ns	1	ns	ns	<5	0.2
16	Silicon	mg/kg	ns	1.29	<1	1	ns	ns	<10	0.4
17	Calcium	mg/kg	1.23	ns	ns	0.5	ns	ns	<1	0.1

Contaminants origin – fuel oil specification by regions. The variation of asphaltenes content in Fig. 2 and Fig. 3 (the increase of it) has in most of the cases only one cause, which is the cross contamination of the VGO with Fuel Oil during its transhipment. This cross contamination can originate either from shorelines (less likely but nonetheless encountered in some places) but most likely from the Fuel Oil OBQ present on board of the vessel in the cargo tanks before loading. It is a usual practice to use a tanker to lift VGO after it had previously carried Fuel Oil, without cleaning its cargo tanks, which is at present time the most common source of contamination of the VGO with asphaltenes.

When compared to each region presented in Table 3, we can observe that the asphaltenes content differs between the regions and does not seem to be dependent of other parameters. Considering that the refineries process the same types of crude oils with certain margins (purchased usually from term contracts), the asphaltenes content varies so slightly through time, but not significantly [18].

Table 2

Examples of Selling specification

No.	Parameter	Units	Case 1	Case 2	Case 3	Case 4	Case 5
1	Density at 15°C	g/l	0.915 max	0.925 max	0.925 max	0.93 max	0.92 max
2	Kinematic Viscosity at 50°C	cCt	50 max	35 max	50 max	50 max	50 max
3	Pour Point	°C	40 max	33 max	40 max	40 max	42 max
4	Flash Point	°C	150 min	-	100 min	100 min	150 min
5	Asphaltenes	mg/kg	500 max	600 max	500 max	400 max	500 max
6	Organic Chlorides	mg/kg	-	-	-	2 max	-
7	Bromine Number at 360°C cut	mgBr/ 100g	-	8 max	5 max	4 max	5 max
8	CCR	% mass	0.5 max	0.4 max	0.4 max	0.8 max	0.4 max
9	Nickel	mg/kg	1 max	1 max	1 max	1 max	2 max
10	Vanadium	mg/kg	1 max	1 max	0.5 max	1 max	2 max
11	Sodium	mg/kg	1.5 max	2 max	1.5 max	1 max	1 max
12	Copper	mg/kg	-	1 max	1 max	-	1 max
13	Iron	mg/kg	2 max	3 max	1.5 max	3 max	1 max
14	Aluminum	mg/kg	-	-	-	-	2 max
15	Silicon	mg/kg	-	5 max	-	1 max	1 max
16	Calcium	mg/kg	-	-	-	-	4 max
17	Zinc	mg/kg	-	-	-	-	-
18	Phosphorus	mg/kg	-	-	-	-	-

Table 3

Fuel oil specification by regions

No.	Parameter	Units	Novorossiysk, Russia	Rotterdam, Netherlands	Ventspils, Latvia	Greece	Iran
1	Statistical qualities collected	-	92	150	133	61	77
2	Density at 15°C	g/l	0.977	1.0002	0.9995	0.995	0.975
3	Kinematic Viscosity at 50°C	cCt	589.9	450.6	650.5	443.2	378.2
4	Pour Point	°C	4	-3	9	6	3
5	Flash Point	°C	132	95	110	77	88
6	Asphaltenes	mg/kg	61000	120000	82000	78000	65000
7	Organic Chlorides	mg/kg	10				
8	CCR	% mass					
9	Bromine Number at 360°C cut	mgBr/ 100g	4		16.5	2	
10	Nickel	mg/kg	23	44	54	16	12
11	Vanadium	mg/kg	46	150	160	190	99
12	Sodium	mg/kg	18	22	24	29	19
13	Copper	mg/kg	<1	<1	<1	<1	<1
14	Iron	mg/kg	30	8	80	7	12

In respect of the other parameters, the asphaltenes content shows the biggest gap in values between VGO and Fuel Oil, which is also the first indication of a Fuel Oil contamination. In present time, it is very difficult to prove with preciseness the point where the VGO was contaminated or picked up another bump in the asphaltene content, but none of the experts in the field can deny that Fuel Oil is the prime cause of contamination of the VGO [S&P Platts]

Developing the model

General assessments: 1) The comparison of the shore/ship asphaltenes content of the Vacuum Gasoil showed a non-linear dependence on the value; 2) The dependence trended to be linked to several factors involved in the transshipment operation like: a) the properties of the previous Fuel Oil cargo carried (density, viscosity, pour point and asphaltenes); b) the discharge performance of the previous Fuel Oil cargo reflected in clingage, ROB/OBQ, remaining cargo in vessel's lines; c) the temperature of the cargo, sea water and ambient during the discharge operation of the previous Fuel Oil cargo; d) vessels particularities (cargo tanks geometry and coating, cargo pumping specification, cargo lines specification)

Factors used: 1) A theoretical approach based on idealistic behaviour and existing theoretical model analogy is impossible due to the complexity of the variables and the limitation of the information available up to the point of making the appropriate decision; 2) The model proposed by us uses the blending equations, empirical data gathered, approximation values and numerical regression in order to predict the increase in asphaltenes content of the VGO cargo loaded on top of the Fuel Oil; 3) The calculation starts with determining the particularities of the vessel. From this, the model makes a supposition of the usual clingage which he considers the base theoretical OBQ. This OBQ is thereafter multiplied by:

a) **Viscosity Factor:** Factor developed from empirical data that considers the possible OBQ increase in dependence with the high viscosity of the Fuel Oil carried as the last cargo. In within the limited values of available data exponential dependence on viscosity of this factor was established (1)

$$F_{Visc} = 1 + 0.051\exp\left(0.2339\left(\frac{\vartheta-\vartheta_{min}}{\vartheta_{min}}\right)\right) \quad (1)$$

b) **Pour Point Factor:** Factor developed from empirical data that considers the possible OBQ increase in dependence with the pour point of the Fuel Oil carried as the last cargo. It is appreciating an exponential dependence of this factor up to limit values of available data (2).

$$F_{pp} = 1 + 0.003\exp\left(2.195\left(\frac{pp - pp_{min}}{pp}\right)\right) \quad (2)$$

To be noted that the factor was limited to a maximum value of 2.81 under the limitations of this model. After that, no matter how much the pour point was increased, the value remains constant, for the limit values of the available data.

c) **Temperature Factors:** Factors developed from empirical data that takes into account the possible OBQ increase in dependence with the cargo temperature carried (in line with the rheological properties of the Fuel Oil), the sea water temperature and the ambient temperature during the last discharge of the Fuel Oil. First and second temperature factors can be appreciated by mean of relation (3) and (4). Here t_{OB} is the temperature of fuel oil during the previous discharge operation and t_{sw} gives the sea ambient temperature.

$$F_{T1} = \frac{1 + 0.1\left(\frac{t_{OB} - 40}{40}\right)^2 + 0.2\left(\frac{t_{OB} - 40}{40}\right)^4 \; for\ \mathrm{t_{OB}} \le 40^0 C}{1 \ \mathrm{for\ t_{OB}} \succ 40^0 C} \quad (3)$$

$$F_{T1} = \frac{1 + \left(\frac{t_{sw} - 20}{20}\right)^2 + \left(\frac{t_{sw} - 20}{20}\right)^4 \; for\ \mathrm{t_{sw}} \le 20^0 C}{1 \ \mathrm{for\ t_{sw}} \succ 20^0 C} \quad (4)$$

d) **Vessel Line Factor**: Factor developed from the empirical data that takes into account the possible OBQ increase in dependence with the Cargo Lines used by the vessel. It uses a polynomial dependence of vessel line factor (F_{Line}) upon active volume of the vessel line (5)

$$F_{Line} = 0.07 V_{line} + 1.2\,10^{-4} V_{Line}^2 \quad (5)$$

e) **Clingage Factor** was developed from the empirical data that considers the usual clingage, which is found on board of the Vessel as the film that adhered to the Bulkheads of the Cargo Tanks.

f) **Sedimentation Factor** can be established from data that considers the increase in sediments in the ROB. It is the case when the Vessel carried out Fuel Oil Cargoes for an extended period, without any Cargo Tanks washings or preparation in between

Applying the model

Based on the statistical data gathered, we have observed the variation of the asphaltene levels in line with the parameters involved and with our proposed factors and tried to depict a dependency towards which the value of the theoretical result would get close enough to the real result.

For this, we have developed a program that uses the data base (existent and with the possibility of extending it) and a specific sets of predictive equations for above presented factors (mostly based on multi-numerical regression with variational tendency). Based on the equations of blending for asphaltenes [15], we have created in the program a short window [Table 4] where the user can input all the available parameters to obtain the critical OBQ. This critical value of OBQ is used later to define the maximum set-value of the asphaltenes level in order to consider the VGO cargo still on specification and acceptable by the receiver. Considering the critical OBQ value as the line that should not be crossed in order to be able to conserve the asphaltenes in the required sale limits, we have define it later on in the model the real OBQ that was responsible for the increment of the asphaltenes value. Since the real OBQ is obtained by the use of industry accepted blending equations, we have considered all errors up to this stage of model to be only negligible as long as they were in the recognized precision arrays for their respective methods of analysis.

Table 4

Model – Blending towards Critical Value

No.	Parameters/Steps	Units	Value
1. Insert parameters of scheduled parcel of VGO			
1	Volume	m³	31775.376
2	Weight	MTA	28890.172
3	Density	g/l	0.9092
4	Asphaltenes	ppm	400
2. Insert quality parameters of OBQ			
5	Density	g/l	0.9892
6	Asphaltenes	ppm	106500
3. Select maximum allowed increasing of asphaltenes content			
7	Increasing of asphaltenes	% weight	**25.00%**
8	Critical value of asphaltenes	ppm	**500.00**
4. Receive critical quantity of OBQ (for inserted quality)			
9	Critical OBQ	% weight	**0.09%**
		m³	**27.552**

On the next stage of the model, we have created an input window to collect all the available parameters for each case, including sufficient items in order to obtain a more comprehensive comparison between the critical OBQ, the real OBQ and the physically measured OBQ. This was a very important stage in our model since it showed an unexpected behavior reporting to the international standard practices. At this stage we also observed the high sensitivity of the VGO during transshipments respect to physically measured OBQ and variations of the contained asphaltenes.

Table 5

Model Factors Input and Comparison

Parameters				Units	Case 1	Case 2	Case 3	Case 4
Statistical data								
On board quantity	Volume			m³	18.2	0	21	17.5
				% vol.	0.05%	0.00%	0.03%	0.08%
	Weight			MTA	17.781	0.000	20.752	17.066
				% w.	0.06%	0.00%	0.03%	0.08%
	Density			g/l	0.9770	0.9892	0.9882	0.9752
	Asphaltenes			ppm	99000	67900	91000	121000
Vessel loaded	Volume			m³	33231.82	32333.12	67872.22	23236.32
				% vol.	99.95%	100.00%	99.97%	99.92%
	Weight			MTA	31071.75	29843.47	63874.54	21391.35
				% w.	99.94%	100.00%	99.97%	99.92%
	Multipliers (Using OBQ par.)			g/l	0.9350	0.9230	0.9411	0.9206
	Asphaltenes			ppm	121	88	152	354
Total figures (real)	Volume			m³	33250.02	32333.12	67893.22	23253.82
	Weight			MTA	31089.53	29843.47	63895.30	21408.42
	Density			g/l	0.9350	0.9230	0.9411	0.9206
	Asphaltenes			ppm	235	108	233	635
Selling limit of Asphaltenes				ppm				
Empirical prediction of asphaltenes								
Empirical parameters	Multipliers (Using OBQ parameters)	Viscosity factor	Viscosity	cSt	382.0	298.0	176.0	312.0
			Factor	-	1.109	1.087	1.064	1.091
		Pour point fac.	Pour point	°C	9	6	12	9
			Factor	-	1.000	1.000	1.027	1.000
		Temp. factors	Cargo temp.	°C	42	39	49	32
			Sea/Ambient	°C	11	30	5	10
			Temp factor 1	-	1.000	1.000	1.000	1.000
			Temp factor 2	-	1.100	1.000	1.232	1.100
		Clingage factor		m³	12.3	15.3	19.3	23.3
		Line factor	Line capacity	m³	43.0	41.3	83.2	35.0
			Vessel lines condition factor	m³	3.01	2.891	5.824	2.45
	Asphaltenes theoretical			ppm	239	129	227	615
	Difference (theory-Real)			ppm	4	21	-6	-20

The model, considered in Table 5 with imputed and computed data for five cases, establishes the difference between theoretical asphaltenes prediction and those real values, obtained in laboratory. Here we were able to adjust and modify the prediction equation (6) as needed, until the results showed the errors to be in within the acceptable set up limits.

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Table 6

Example of Calculation

Parameters				Units	Case 19
Statistical data					
On board quantity			Volume	m^3	7.2
On board quantity			Volume	% vol.	0.02%
On board quantity			Weight	MTA	7.122
On board quantity			Weight	% w.	0.02%
On board quantity			Density	g/l	0.9892
On board quantity			Asphaltenes	ppm	**106500**
Vessel loaded			Volume	m^3	31775.376
Vessel loaded			Volume	% vol.	99.98%
Vessel loaded			Weight	MTA	28890.172
Vessel loaded			Weight	% w.	99.98%
Vessel loaded			Multipliers (Using OBQ parameters	g/l	0.9092
Vessel loaded			Asphaltenes	ppm	**400**
Total figures (real)			Volume	m^3	31782.576
Total figures (real)			Weight	MTA	28897.294
Total figures (real)			Density	g/l	0.9092
Total figures (real)			Asphaltenes	ppm	**550**
Selling limit of Asphaltenes				ppm	
Empirical prediction of asphaltenes content					
Empirical parameters	Multipliers (Using OBQ parameters	Viscosity factor	Viscosity	cSt	420.0
Empirical parameters	Multipliers (Using OBQ parameters	Viscosity factor	Factor	-	1.120
Empirical parameters	Multipliers (Using OBQ parameters	Pour point factor	Pour point	°C	12
Empirical parameters	Multipliers (Using OBQ parameters	Pour point factor	Factor	-	1.027
Empirical parameters	Multipliers (Using OBQ parameters	Temp. factors	Cargo temp.	°C	48
Empirical parameters	Multipliers (Using OBQ parameters	Temp. factors	Sea/Ambient temp	°C	-10
Empirical parameters	Multipliers (Using OBQ parameters	Temp. factors	Temp factor 1	-	1.000
Empirical parameters	Multipliers (Using OBQ parameters	Temp. factors	Temp factor 2	-	1.532
Empirical parameters	Multipliers (Using OBQ parameters	Clingage factor		m^3	27.8
Empirical parameters	Multipliers (Using OBQ parameters	Line factor	Line capacity	m^3	42.9
Empirical parameters	Multipliers (Using OBQ parameters	Line factor	Vessel lines condition factor	m^3	3.003
Empirical parameters	Asphaltenes theoretical			ppm	**560**
Empirical parameters	Difference (theory-Real)			ppm	**10**

The model constraints were concentrated in a precision marker known as repeatability [13], since it is the most restrictive reference variable available in the international standard practices and also acceptable by the Petroleum Trading Industry as inserted in most of the contractual clauses. We show that by using all the proposed factors and considering the way each one influences the asphaltene changing during the transshipment of the VGO, we have obtained the following basic model equation:

$$P_{OBQ} = P_{0(BaseOBQ)}(F_{visc} + F_{pp} + F_{T1} + F_{T2}) + P_{line}F_{line} + P_{Cling} \quad (6)$$

In Table 6 we can see the implementation in model interface of equation (6) by showing for a specific case the calculation with the results obtained.

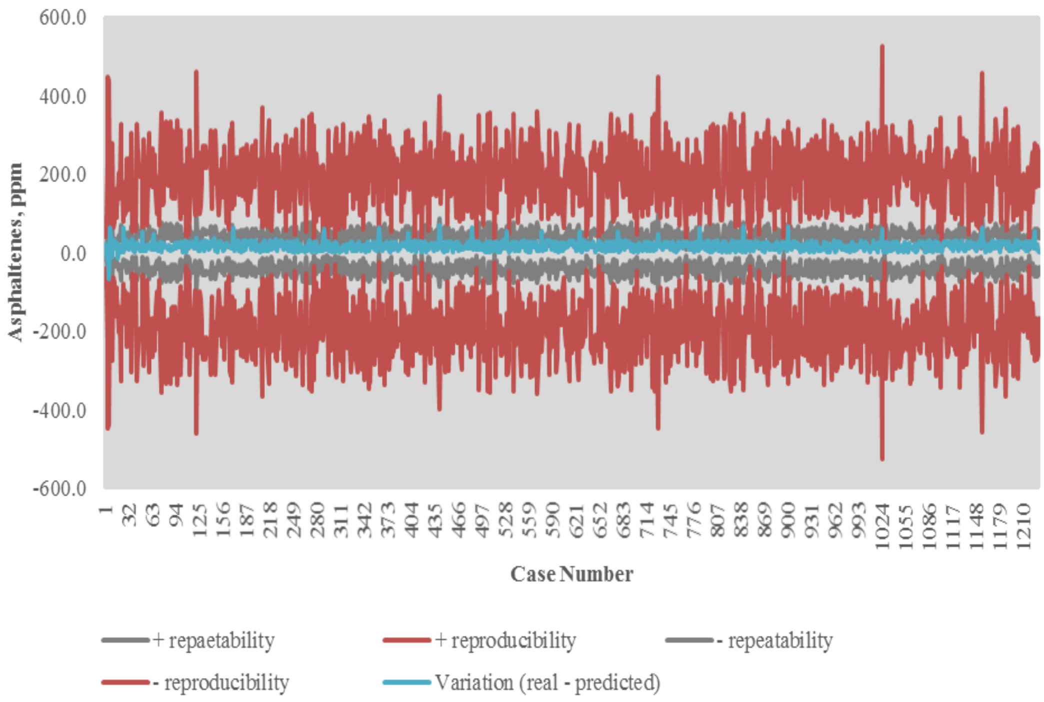

Fig. 4. State of repeatability, reproducibility and real predicted variation for cases from Fig. 2

The model simulations for cases given in Fig. 2 and Fig.3 are concentrated in terms of repeatability, reproducibility and real predicted variation (difference) in Fig. 4 and Fig. 5.

Fig. 5. State of repeatability, reproducibility and real predicted variation for cases from Fig. 3

Results and discussions

In this study, we can observe that the prediction for the asphaltene content are comparable with the results obtained on ship's composite after loading, in within the limit of precision (the limit of precision was taken from the usual method for asphaltene content testing – Total 642)

Applying the proposed model to the studied cases, we observe that the predictions made of the asphaltene content would have indicated the high risk of contamination of the VGO with Fuel Oil, even though the inspection party followed the latest international standard practices (see Table 7).

The more reliable result obtained through this model could be explained by the fact that it takes into consideration factors which the latest international standard practices do not address, like the specific particularities of the vessel, the more detailed parameters of the last cargo carried and the conditions in which it was discharged and also information regarding the contractual quality clauses of cargo transhipped

Table 7

Example of Calculation

Cargo contamination by OBQ - Asphaltenes

Parameter	Units	Predicted Real OBQ	Loaded cargo	Total
Volume	m³	44.153	31,731.223	31,775.376
	% vol.	0.14%	99.86%	100.00%
Weight	MTA	43.676	28,850.028	28,893.704
	% weight	0.15%	99.85%	100.00%
Density	g/l	0.9892	0.9092	0.9093
Quality				
Asphaltenes	ppm	106500	400	560
			Increasing of Asphaltenes content	161ppm [40.25%]
			Critical (Max. allowed) Asphaltenes content, ppm	500
			Reserve to the critical value, ppm	OUT!
			RISK	Cargo OFFSPEC

Conclusions

The presented model is very useful as a tool to predict the critical calculated OBQ towards which you could load on top or not. The critical OBQ cannot any longer be considered as the measured OBQ since in the present days, the OBQ inspections are limited to deck level via vessel’s vapor lock valves under inert conditions, using hermetic appliances. The model is very useful in nowadays midstream market because it helps to: i) minimize contamination claims which are highly detrimental and damaging towards every party involved, ii) optimize the vessel’s cargo changeover of tanker carriers based on a more field-realistic approach, iii) minimize the production of Slops and Washings from Cargo Changeover, iv) reduce the demurrages caused by delays for unexpected cargo tanks rejections, cargo rejections or claims, v) safeguard the quality of the commodity carried and raise the awareness of the contamination prevention importance instead of being forced to take just corrective actions, which are much more higher in extra cost generating. In addition, the model has the capacity to improve provided that more data available is processed and the data filters are applied accordingly.

REFERENCES

[1] API MPMS Chapter 17.2 Measurement of Cargoes On Board Tank Vessels (includes Errata 1 dated April 2000) 2nd Edition | May 1999 | Reaffirmed: September 2011 2-Year Extension: May 2016.
[2] API MPMS Chapter 17.4 Method for Quantification of Small Volumes on Marine Vessels (OBQ/ROB) 2nd Edition | September 2016.
[3] Energy Institute, London - Hydrocarbon management HM 50 Guidelines for the cleaning of tanks and lines for marine tank vessels carrying petroleum and refined products, October 2018, 5th edition.
[4] API MPMS Chapter 17.8 Guidelines for Pre-Loading Inspection of Marine Vessel Cargo Tanks and Their Cargo-Handling Systems 2nd Edition | August 2016.
[5] Energy Institute, London - Hydrocarbon management HM 95 Guidelines for marine petroleum cargo superintendents, January 2016, 1st edition.
[6] BP Tank Cleaning Guide 2018.
[7] API MPMS Chapter 8.1, Standard Practice for Manual Sampling of Petroleum and Petroleum Products (ASTM D4057).
[8] ASTM D4052 - 18a Standard Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter.
[9] ASTM D95-13(2018) Standard Test Method for Water in Petroleum Products and Bituminous Materials by Distillation.
[10] ASTM D7157-18 Standard Test Method for Determination of Intrinsic Stability of Asphaltene-Containing Residues, Heavy Fuel Oils, and Crude Oils (n-Heptane Phase Separation; Optical Detection).
[11] ASTM D4294-16e1 Standard Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry.
[12] ASTM D93-18 Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
[13] ASTM D6560-17 Standard Test Method for Determination of Asphaltenes (Heptane Insolubles) in Crude Petroleum and Petroleum Products 1, 2.
[14] API MPMS Chapter 9.1 Standard Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method (ASTM D1298).
[15] James G. Speight, *Rules of Thumb for Petroleum Engineers*, Chapter 42, Blending and Mixing, 3rd March 2017.
[16] Hong E., P., Watkinson. A study of asphaltene solubility and precipitation, *Fuel*, 83, 14–15, (2004), 1881-1887.
[17] B. J., Abu, T. Maen, M. Husein, Adsorption of asphaltenes from heavy oil onto in situ prepared NiO nanoparticles, *Journal of Colloid and Interface Science*, 378, 1, (2012), 64-69.
[18] X. Li, P. Chi, X. Guo, Q. Sun, Effects of asphaltene concentration and asphaltene agglomeration on viscosity, *Fuel*, 255, 1 November 2019, 115825.
[19] API MPMS Chapter 8.3 Standard Practice for Mixing and Handling of Liquid Samples of Petroleum and Petroleum Products (includes Errata 1 dated March 1996) (ASTM D5854).
[20] API MPMS Chapter 7, 1st Edition, June 2001, Reaffirmed: February 2012 2-Year Extension: March 2017.
[21] API MPMS Chapter 3.1A, 3rd Edition August 2013.