Proposed Equations for Crude Oil Theft Volume (And Volume-Share) Estimations in Oil Transport Pipeline Network

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ABSTRACT

In Nigeria, for example, Crude oil theft is on an industrial scale. Estimates of how much oil is stolen from oil transport pipeline in Nigeria vary widely because of lack of fool-proof measures to monitor pipelines, absence of up-to-the minute technology to determine the actual production, tepid attitude to the policing of the pipeline and the strong enabling environment corruption and fraud, in the oil sector.

This work presents an equation, based on reconciliation factor, for estimating crude oil theft volume, and model for crude oil theft volume-share among oil producers utilizing a pipeline network belonging to a major producer. The model formulated tries to allocate crude oil stolen volume proportionally to all flow stations and injectors connected to a pipeline network pro rata their injection and pipeline exposures. The model is also formulated to share the loss in a manner that consider the varying BS&W of the "dry crude" and/or "wet crude" delivered into the oil transport pipeline network.

Data from an X terminal pipeline network, experiencing crude oil theft, in the Niger Delta are used to illustrate the applicability of the models.

Keywords: Crude oil theft volume estimations, Oil theft volume-share calculations, Transport pipeline

INTRODUCTION

The basic story of how Nigeria's crude goes missing has been told for years. To steal oil, thieves tap into pipelines and other infrastructure in the Niger Delta. They then pump the oil onto waiting barges and boats. Some of it is refined locally while larger vessels carry the rest abroad as reported by Christina Katsouris and Aaron Sayne [1]. Crude oil theft is on an industrial scale in Nigeria. Oil companies in Nigeria operate in astonishingly inclement conditions, unlike their counterparts in other countries which are assured of the security of their pipelines; those in Nigeria have to endure vandalisation of theirs as well as other irritations. Theft of oil in oil transport pipeline in the Niger Delta, especially in the Eastern flank made up of Rivers State and Bayelsa State, has risen alarmingly; the impact of oil theft in Nigeria in recent times has been so devastating that oil Multinationals; Shell and Agip, were losing 190, 000 bbls of crude daily from oil fields in southern Bayelsa State [2].

The Minister of Finance, Dr. Ngozi Okonjo-Iweala, recently lamented that the country was losing 400,000 bbls of crude oil per day because of crude theft, illegal bunkering, vandalism of infrastructure and halt in production. In addition, the Minister of Petroleum Resources- Mrs. Diezani Alison-Madueke, said, "Nigeria might not recover from the negative impact of crude theft and pipeline vandalism in the next 20 years or more. She stated that the nation was producing 2.3 million barrels of crude oil per day as against its daily production benchmark of 2.567 million barrels in the 2013 budget. Also, the Shell Petroleum Development Company's Manager in Nigeria said, "Our biggest worries are crude oil theft

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and illegal refineries. They are bringing down the economy. Nigeria loses 150, 000 barrels of crude oil per day amounting to $6.1 billion annually to oil theft" [3].

In oil theft story in Nigeria, the biggest controversy is the actual loss figure because of lack of fool proof measures to monitor pipelines, absence of up-to-the-minute technology to determine the actual oil production and tepid attitude to the policing of the pipelines. In this light, one may wonder then the level of disagreement of crude oil theft volume-share among oil producers utilizing a pipeline network belonging to a major producer. There is no published, but there may exist in-house models unknown to the public, models for crude oil theft estimations and volume-share among oil parties which could have been revised.

This work therefore presents simple equations for estimating crude oil theft volume and oil theft volume-share among oil producers making use of export pipeline network owned by an oil giant. The oil theft volume-share model formulated allocates crude oil stolen volume proportionally to all flow stations and injectors pro rata their injections and pipeline exposures. The model is also formulated to allocate the loss in a way that consider the varying BS&W of the mixture of the "dry crude" and/or "wet crude" delivered into an oil transport pipeline network. The applicability of the models is illustrated using data from an X terminal pipeline network in the Niger Delta experiencing crude oil theft.

ALLOCATION THEORY

Measurements in the flow stations are less accurate because they are used for field control reasons only. The highest accuracy is for fiscal purposes; where the custody of product changes hands and the recipient pays the provider. Fiscalisation takes place at terminals to measure exports; transfers to refineries and other customers, plus "third party" transfers into a pipeline network belonging to someone else. Fiscal metering is normally accurate to +/- 0.25% for liquids and 1% for gas. Field measurements are typically +/- 10%. Allocation- which is the process of assigning the proper portions of aggregated product flows back to individual source streams, owners, leases or measurement point, is a standard method that is agreed upon and used by contracting parties [4]. Individual allocation meters determine the portion of flow that is attributable to an individual source stream. The allocation meters may or may not meet custody transfer standards, although the total production should be determined with custody transfer quality systems and procedures. The allocation volume to each measurement point is established by applying a correction factor or reconciliation factor or experience factor to the field measurements. This factor is derived by dividing the fiscal measurements made at custody transfer point, by the sum of the measurement taken in the field. The reason for using such a reconciliation factor is because fiscal measurements are much more accurate than field measurement. Note that the reconciliation system captures any volumes lost due to equipment malfunctions which cause loss of production, such as an individual well or a flow station trip e.t.c, also any losses due to a line leak are calculated and reported; as are the volumes associated with shrinkage due to any remaining gas coming out of solution in the oil. It also caters for any inaccuracies in determining the water content of the fluid. All of these aspects typically result in "reconciliation factors, RF," between 0.92 – 0.99, which is considered to not justify additional measures. When the RF does drop closer to 0.92 investigations normally take place to find and correct the reason [5]. The cause is normally attributable to such events as a malfunctioning meter giving inaccurate reading, or a water cut device not working correctly; sometimes due to leaking valves, or similar.

The expected models formulations are therefore based on the basic assumptions below;

1. Net oil calculation is performed by industrial standards.

2. Reconciliation factor before oil theft period is determined by looking at the historical trend within the first five years of delivery and receipt after pipeline installation.
3. BS&W is determined following API procedure.
4. Total pipeline length from various flow stations on a pipeline network is known.

FORMULATION OF THE PROPOSED CRUDE OIL THEFT VOLUME EQUATION

The fluids flowing from flow stations to oil terminal are sometimes "dry oil" and/or "wet oil" with varying properties. The flowing oil volume measured at the flow station and at the terminal will have little/large discrepancy due to measurement uncertainties and pipeline leakages;

The unaccounted oil volume = losses due to measurement uncertainties + losses due to pipeline leakages (i.e. bunkering & sabotage).

Let;

Total crude oil volume at flow stations be V_F

Total gross volume at flow stations be V_{GF}

Total crude oil volume at Terminal be V_T

Total gross volume at Terminal be V_{GT}

Reconciliation factor before pipeline leakages be RF_b

Reconciliation factor during theft be RF_d

For crude oil flowing from fiscal metering/field measurement point A to fiscal metering point B through a non-leaked pipeline network, the unaccounted crude oil volume will definitely be due to uncertainties relating to the accuracies associated with measurement devices, device calibration, sample gathering and analysis, variable operating conditions, etc. These uncertainties are for single-phase specific volume determination points of specific fluids (oil, gas, or water) or for combinations of two or more such points. These uncertainties do not relate to comparisons of two or more measurement points, such as comparison of inlet volumes to outlet volumes. Such comparisons are typically expressed as proration factors, allocation factors, or metering differences.

Though these uncertainties do not relate to comparisons of two or more measurement points, such as comparison of inlet volumes to outlet volumes, but for a non-leak pipeline one can roughly determine the unaccounted volume factor due to measurement uncertainties by subtracting the RF_b from unity. That is;

Unaccounted volume factor due to measurement uncertainties = $1 - RF_b$

Therefore, unaccounted volume due to measurement uncertainties = Total oil volume at flow stations $*(1-RF_b) = V_F*(1-RF_b)$ ……………………. 1

The uncertainties are relevant to equipment at the time of installation. No uncertainty adjustment is required to account for the effects of multiphase fluids, wear, sludge or scale buildup, etc., as it is accepted that such conditions would constitute a bias error to be monitored and accounted for through the use of proration factors, allocation factors.

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Losses due to Pipeline Leakages (or Oil Theft)

For crude oil flowing from fiscal metering/field measurement point A to fiscal metering point B through a leaked pipeline network, the unaccounted crude oil volume factor (oil theft volume factor) can be estimated by;

Oil theft volume factor = RF_b - RF_d …………………… 2

Note that; $RF_{during\ theft}$ = Measured gross volume at terminal / (Total measured gross volume at Flow stations * $RF_{before\ theft}$).

That is;

$RF_d = V_{GT}/(V_{GF}*RF_b)$ …………………… 3

This ensures the complete exclusion of error due to measurement uncertainties in the estimation of oil theft volume.

Therefore Oil theft volume = (Total net delivery from Flow stations / RF_b) *oil theft volume factor

That is; Crude oil theft volume,

V_{ot}, = $(V_T/RF_b) * (RF_b - RF_d)$ …………………… 4

FORMULATION OF THE PROPOSED CRUDE OIL THEFT VOLUME-SHARE EQUATION

Some oil fields have volumes too small to justify having pipelines to their own terminals. In this case the gathering network belonging to a nearby major producer is used. The fluids flowing from flow station to oil terminal are sometimes “dry oil” and/or “wet oil” with varying properties. Simultaneous flow of two or more phases of fluid will occur in almost all the pipelines. the flow regime of oil-water phase flow could be similar to the flow regimes in horizontal gas-liquid flow described by Brill and Beggs [6], - segregated flows, in which the two phases are for the most part separated; Intermittent flows, in which the phases are alternating; distributive flows, in which one phase is dispersed in the other phase.

Basically, the flow in oil transport pipeline is mostly distributive; the dispersion of oil-water in distributive flow is either water in oil or oil in water. When oil theft is experience within the pipeline network, dividing the stolen oil crude volume among oil parties utilizing an oil pipeline network owned by a major oil player will be quite challenging because of the varying crude oil qualities injected into the pipeline and the back-calculated approach employed to a non-metered flow station delivery.

Therefore, the oil theft volume to be allocated proportionally to all flow stations and injectors pro rata their Injection and Pipeline exposure is proposed. Because of the varying crude oil qualities (especially the BS&W) and what is being stolen is an emulsion, i.e. oil in water, when water is the dominant phase or water in oil, when oil is the dominant phase, the oil theft volume should first be divided into two parts by finding the range value of oil fractions of all flow stations.

Let’s assume that;

The BS&W fraction for flow station i = $BS\&W_i$

The oil fraction for flow station i = $F_{oi} = (1 - BS\&W_i)$

The pipeline factor for flow station i = $PLf_i = \frac{Total\ Length\ of\ pipeline\ to\ terminal\ of\ flow\ station\ i}{Total\ length\ of\ pipeline\ network}$

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The range of oil fraction stolen from the pipeline network;

R_{of}, = Max. (F_{oi}) – Min. (F_{oi}) ……………………. 5

The oil theft volume from the pipeline network = V_{ot}

Dividing the oil theft volume into two parts by using R_{of} results into;

$V_{ot}(1-R_{of})$ and $V_{ot}(R_{of})$.

Given that there are n numbers of flow stations connecting to a pipeline network.

Theft oil volume-share for Flow station$_i$, $V_{ot(share)i}$;

$$=V_{ot}(1-R_{of})\left[\frac{F_{oi}*PLf_i}{\sum_{i=1}^{n}(F_{oi}*PLf_i)}\right]+V_{ot}*(R_{of})\left[\frac{(1-F_{oi})*PLf_i}{\sum_{i=1}^{n}((1-F_{oi})*PLf_i)}\right] \quad \ldots\ldots\ldots\ldots 6$$

Application of the Oil Theft Volume & Volume-Share Equations to a Field Case

The X Terminal pipeline network in the Niger Delta, experiencing oil theft which may occur at various points along its pipeline network, owned by an oil giant receives crude oil from its various non-fiscalised flow stations, and also from 3rd parties, via a 24” pipeline. Table 1 shows the crude oil volume with its BS&W delivery for a particular month from the various flow stations to the terminal. The total gross volume (oil & water) from the flow stations is put at 6,660, 538 barrels. The terminal net receipt is 2,201,886 barrels with BS&W of 58% (gross volume = 5,281,545 barrels). The pipeline lengths from the various flow stations to terminal are also presented in same Table 1. The total length of pipeline network is 402.41 Km.

Table 1. Flow stations’ pipeline lengths, BS&W, and Gross Delivery

Flow Stations	*Gross Delivery*	*BS&W %*	*Net Delivery*	*Pipeline Length to Terminal*
	BBLS		*BBLS*	*Km*
1	155960	22.86	120314	180.8
2	164760	0.029133	164712	180.8
3	228080	31.86	155409	163.5
4	1261469	24.26	955394	141.5
5	257815	0.23	257216	141.5
6	984211	28.61	702624	99.6
7	718905	39.65	433879	107
8	380032	62.93	140885	109.5
9	407795	60.22	162202	57.5
10	438269	53	205996	39.3
11	861314	58.46	357757	92.5
12	48140	55	21664	92.5
13	753788	63.97	271582	42
Total	*6660538*		*3949634*	

Before bunkering activities along the pipeline network, the gross RF used to be 0.998 which can be considered as RF before oil theft, RF_b.

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Estimation of the crude oil theft volume, by applying equation 3 and 4, gives;

$RF_d = V_{GT}/(V_{GF}*RF_b)$ ……………………. 3

= 5281545 /(6660538*0.998) = 0.7945

Crude oil theft volume,

V_{ot}, = $(V_T/RF_b) * (RF_b - RF_d)$ ……………………. 4

= (2201886 /0.998)*(0.998-0.7945)

= 448,981.76 barrels

Applying equations 5 and 6, and using Microsoft Excel® program, Theft oil volume-shares for the various Flow stations are presented in Table 2. The oil theft volume-share ranges from 16,149.18 barrels to 51019.62 barrels.

V_{ot}= 448,981.76 barrels; $R_{of} = 0.6395$; $\sum_{i=1}^{n}(F_{oi} * PLf_i) \approx 2.4665$; $\sum_{i=1}^{n}((1 - F_{oi}) * PLf_i) \approx 1.1310$.

Table 2. Calculations of oil theft volume-shares for the various flow stations

Flow Stations	*BS&W %*	*Oil Fraction* F_{oi}	*Pipeline Length to terminal, Km*	*Pipeline Factor,* PLf_i	$1\text{-}F_{oi}$	PLf_i*Foi	*PLfi*(1-Foi)*	$V_{ot(share)i}$ *Bbls*	*Vot(share)i %*
1	22.86	0.7714	180.8	0.4492	0.2286	0.3465	0.1027	48807.44	10.9
2	0.02	0.9998	180.8	0.4492	0.0002	0.4491	0.0001	29493.48	6.6
3	31.86	0.6814	163.5	0.4062	0.3186	0.2768	0.1294	51019.62	11.4
4	24.26	0.7574	141.5	0.3516	0.2426	0.2663	0.0853	39124.84	8.7
5	0.23	0.9977	141.5	0.3516	0.0023	0.3507	0.0008	23221.54	5.2
6	28.61	0.7139	99.6	0.2475	0.2861	0.1767	0.0708	29565.86	6.6
7	39.65	0.6035	107	0.2658	0.3965	0.1604	0.1054	37287.49	8.3
8	62.93	0.3707	109.5	0.2720	0.6293	0.1008	0.1712	50081.37	11.2
9	60.22	0.3978	57.5	0.1429	0.6022	0.0568	0.0860	25569.63	5.7
10	53	0.47	39.3	0.0976	0.5300	0.0459	0.0517	16149.18	3.6
11	58.46	0.4154	92.5	0.2298	0.5846	0.0955	0.1343	40372.32	9.0
12	55	0.45	92.5	0.2298	0.5500	0.1034	0.1264	38875.41	8.7
13	63.97	0.3603	42	0.1043	0.6397	0.0376	0.0668	19413.59	4.3
	R_{of}	0.6395				2.4665	1.1310		100.0
	V_{ot}	448,981.76	Total Pipeline network = 402.5						

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CONCLUSION

Estimates of how much oil is stolen from oil transport pipeline, especially in Nigeria, vary widely because of lack of fool-proof measures to monitor pipelines, absence of up-to-the minute technology to determine the actual production, tepid attitude to the policing of the pipeline and the strong enabling environment corruption and fraud, in the oil sector. Based on reconciliation factor, an equation for estimating crude oil theft volume is formulated, and model for crude oil theft volume-share among oil producers utilizing a pipeline network belonging to a major producer is proposed. Application of the models to a field case estimate crude oil theft volume as 448, 981.76 barrels. The oil theft volume-share ranges from 16,149.18 barrels to 51019.62 barrels.

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Conflict of Interest

The author declares that there is no conflict of interests regarding the publication of this article.

REFERENCES

[1] Christina, K., & Sayne, A. (2013). *Nigeria's Criminal Crude: International Options to Combat the Export of Stolen Oil*. London: Chatham House. http://www.chathamhouse.org/sites/files/chathamhouse/public/Research/Africa/0913pr_nigeriaoil.pdf

[2] PMNEWS–Funsho, B. (2013). *Oil theft in the Niger Delta.* Available at: http://trendyafrica.com/oil-and-gas/oil-theft-in-the-niger-delta/

[3] Emma, A. (2013). *Oil: The conspiracy that robs Nigeria of billions of dollars*. Available at: http://www.vanguardngr.com/2013/08/oil-the-conspiracy-that-robs-nigeria-of-billions-of-dollars/

[4] API (1993). *MPMS Chapter 20.1 – Section 1, Allocation Measurement*, 1st Ed. USA: API

[5] Shaxson, N. (2009). *Nigeria Extractive Industries Transparency Initiative.* London: Chatham House.

[6] Brill, J. P., & Beggs, H. D. (1978). *Two-Phase Flow in Pipes*. Tulsa, OK: University of Tulsa.