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ANALYSIS OF LOSSES AND LEAKS DURING THE TRANSPORT AND STORAGE OF PETROLEUM PRODUCTS LEAVING THE ANGO-ANGO BASE (MATADI) VIA SEP CONGO PIPELINES PL-46 AND PL-66 TO KINSHASA (2018-2022)

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ABSTRACT

The transportation and storage of petroleum products via multi-product pipelines constitute a strategic link in energy supply. However, these systems remain exposed to significant losses and spills. This study analyses the physical and economic losses associated with the transportation and storage of petroleum products, focusing on the phenomena of leaks, evaporation, corrosion, loosening of connections, sabotage and batch contamination. The methodological approach is based on a descriptive and comparative statistical analysis, supplemented by a cause analysis using the FMEA method (Failure Modes, Effects, and Criticality Analysis). The results indicate that physical losses can account for between 0.5% and 2% of transported volumes, while the volumes of contaminated products in multi-product pipelines can reach 1% to 3% of the total flow, leading to downgrades as well as additional costs related to storage and reprocessing. Beyond the economic impacts, petroleum product spills cause major environmental consequences, including soil and water resource pollution, as well as an increased risk of fire and explosion.

Keywords: losses, spillage, transport, storage, petroleum products, pipelines.

INTRODUCTION

The socio-economic approach of the 21st century highlights the central role of oil energy, considered a sine qua non condition for the development of modern societies [9]. In a country like the Democratic Republic of Congo, all sectors of activity heavily depend on energy supply to ensure their operation, support economic growth and improve the living conditions of the population [25]. However, the efficiency of this supply remains closely linked to the quality of oil infrastructure, particularly those dedicated to refining, transport and storage [14]. Despite increasing demand, the growth of national supply volume remains limited by logistical constraints, especially the insufficiency of distribution means within the country [19].

In this context, reducing petroleum product losses emerges as a major challenge for companies in the sector [13]. Transport and storage are indeed critical stages where significant losses frequently occur due to phenomena such as evaporation, leaks, corrosion, technical failures, or human errors. Added to this are issues of cross-contamination between batches in multi-product pipelines, causing downgrades and additional management costs [23]. These losses have both economic and environmental repercussions [23],[26]. They not only lead to a reduction in marketable volumes and an increase in operational costs, but also contribute to soil, air, and water pollution, while increasing the risks of fire and explosion. In the face of these challenges, companies are required to develop optimisation strategies that incorporate risk management and the improvement of logistical performance [5]. It is within this framework that the present study is positioned, focusing on SEP Congo, a company specialised in oil logistics in the Democratic Republic of Congo [17],[19]. The company manages the reception of imported hydrocarbons, their transport via pipelines, and their storage before distribution to partners. The transport system under study notably relies on the PL-46 and PL-66 pipelines connecting the Ango-Ango base to Matadi and on to Kinshasa, as well as the infrastructures serving Nd'jili International Airport.

The main objective of this research is to analyse, quantify and characterise the losses and leakages of petroleum products occurring during transport and storage between 2018 and 2022 [8],[17],[19]. More specifically, it aims to identify the main causes of these losses, assess their economic and environmental impacts, and propose appropriate optimisation measures. The value of this study lies in its contribution to improving logistical performance and reducing losses in a context marked by infrastructural constraints [17],[19],[25]. It is based on the hypothesis that physical losses generally range between 0.5% and 2% of the transported volumes, while cross-contamination between batches can reach 1% to 3%, depending on operational and maintenance conditions [8],[13],[19],[20],[22],[24]. Thus, several methods can be used to detect leaks during pipeline maintenance; these include: sensor-based detection methods, data-driven methods guided by software algorithms, and model-based statistical detection methods. [27-31].

MATERIALS AND METHODS

This study adopts a quantitative approach aimed at analysing the losses and spillage of petroleum products during their transport and storage. The methodological approach is based on two complementary axes: a descriptive and comparative statistical analysis of losses, as well as a cause analysis based on the FMEA method [2],[5],[12]. The statistical analysis relies on operational data from volumetric balances provided by SEP Congo [4]. The variables studied include pumped and received volumes, volumetric losses, loss rates (%), contaminated volumes, incident frequency and associated costs. The data processing allowed for the determination of statistical indicators such as means, standard deviations, minimum and maximum values, as well as the performance of comparative analyses according to periods, types of products and infrastructures [8],[19]. The equipment and tools used include operational reports (volume summaries), loss tracking tables (%), time-based charts for trend analysis, as well as Excel software for data processing, analysis and visualisation. Additionally, the FMEA (Failure Modes, Effects and Criticality Analysis) method was applied to identify and prioritise the causes of losses [2]. The main failure modes analysed are leaks due to corrosion, sabotage or perforation of pipelines, seal defects in joints and overpressures [8],[13],[15],[16],[19].

Romanian Journal of Petroleum & Gas Technology
Vol. VII (LXXVIII) • No. 1/2026

Each failure was evaluated according to three criteria: severity, frequency, and detectability. The level of criticality was determined by calculating the Risk Priority Number (RPN), allowing corrective actions to be prioritized [1],[8],[11]. The integration of these approaches, combining operational data, computer tools and risk analysis methods, allows for a reliable quantitative assessment of losses and the identification of critical factors, thus providing a solid basis for optimising the performance of the petroleum products transport and storage system [13],[18], [21-24].

RESULTS AND DISCUSSIONS

It should be noted that SEP CONGO, with 2 six-inch pipelines leaving from Ango-Ango to the Masina base, 3 ten-inch pipelines leaving from the Masina base to the Vrac city, and 1 ten-inch pipeline, ensures the large-scale transport of petroleum products. Nevertheless, the company has recorded several losses of petroleum products during pipeline transport during pumping operations from the Ango-Ango and Masina bases, also when there is contamination of the products in the multi-product pipeline, and in the event of corrosion-related perforation of the pipeline due to weather conditions. [9]

Statistical analysis of losses

Descriptive and comparative statistical method

Change in the quantity of products pumped through pipelines PL-46 and PL-66 from 2018 to 2022 (Ango-Ango Base) are revealed in the Table1 and Table 2.

According to Table 1, during the development period, we note that the PL-46 is more exploited with a total of 1,931,748 m³ than the PL-66 with 1,579,977 m³. It also emerges from this table that the total volumes pumped for each product show regressive trends. This seems quite evident given the graphical illustration of the table in Figure 1.

Table 1. *Evolution of pumped volume quantity (in m³) per year – PL46 and PL66.*

PL	Products	2018	2019	2020	2021	2022	TOTAL
PL 46	Diesel	0	1 648	19 758	18 699	15 843	55 948
	Kerosene	1 756	160 881	141 132	134 813	143 335	581 917
	Petrol	306 950	238 064	271 852	250 485	226 532	1 293 883
SUBTOTAL		308 706	400 593	432 742	403 997	385 710	1 931 748
PL 66	Diesel	380 601	289 673	226 268	221 951	221 840	1 340 333
	Kerosene	1 431	2 127	4 725	13 476	8 235	29 994
	Petrol	35 766	64 101	36 270	32 415	41 098	209 650
SUBTOTAL		417 798	355 901	267 263	267 842	271 173	1 579 977
TOTAL		726 504	756 494	700 005	671 839	656 883	3 511 725

The observation remains the same from 2018 to 2022, the pumped volume continues to increase, except for the last three years which are characterised by a decrease in pumped products due to informal sectors.

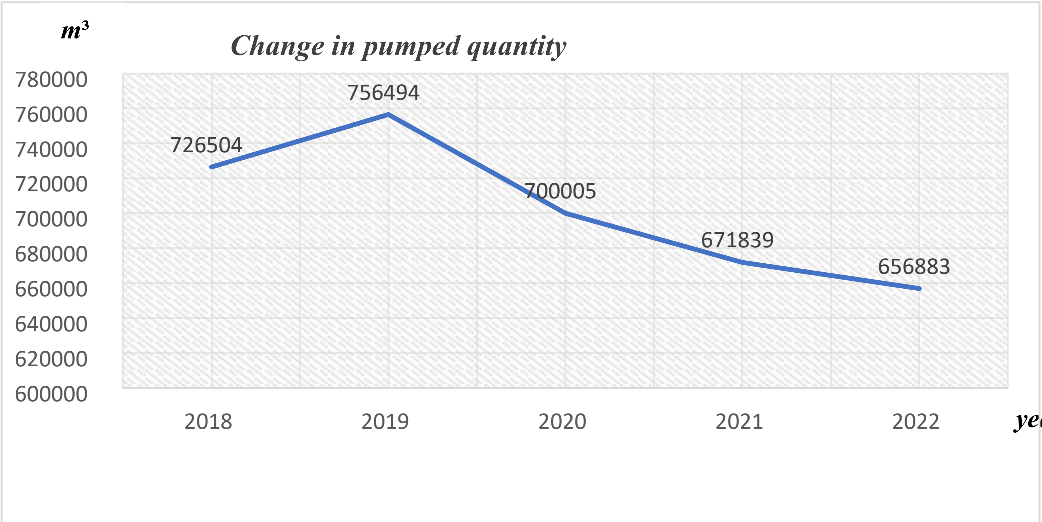


Figure 1. *Evolution of the total quantities of all products pumped over the past five years PL-46 & PL-66.*

Table 2. *Total pumped volume by PL-46 and PL-66 product.*

Products	**2018**	**2019**	**2020**	**2021**	**2022**	**TOTAL**
Diesel	380601	291321	246026	240650	237683	1396281
Kerosene	3187	163008	145857	148289	151570	611911
Petrol	342716	302165	308122	282900	267630	1503533
TOTAL	726504	756494	700005	671839	656883	3511725

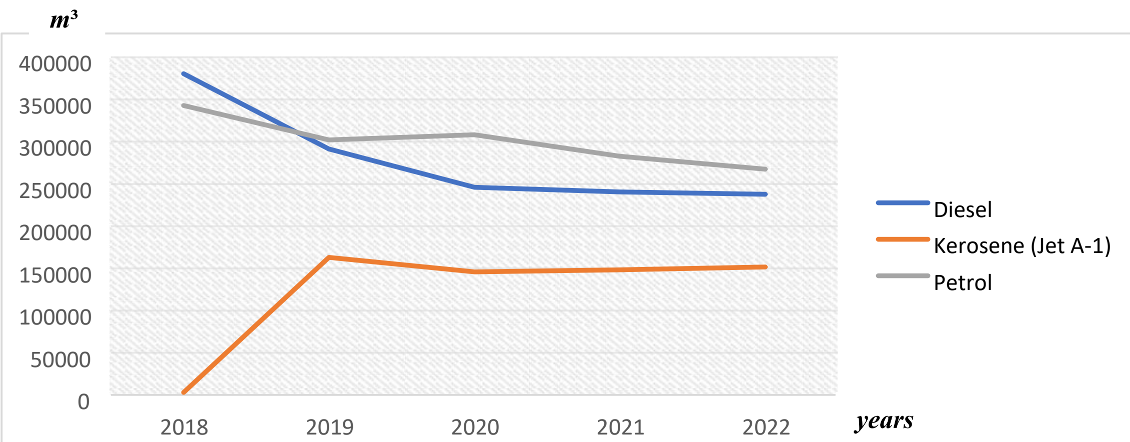


Figure 2*. Evolution of the curve of total quantities of each product pumped over five years.*

Figure 2 shows all the totals of each product pumped from two pipelines. It is evident that there is a decrease in each product extracted each year. This is due to informal sectors as well as losses in pumped volume.

Evolution of the quantity of products received by pipeline in m³ from 2018 to 2022 (Masina Database)

Table 3 reveals to us the evolution of product reception, and we note that PL-46 at the Masina base received a high quantity of products with a total of 1,929,424 m^3 while PL-66 only received 1,576,012 m^3. It also emerges from this table that the total volumes received for each product have a declining trend, which appears even more evident in the graphical illustration of the Figure 3.

Table 3*. Quantity of volume received (in m³) per year – PL-46 & PL-66.*

PL	Products	2018	2019	2020	2021	2022	TOTAL
PL 46	Diesel	0	1 648	19 714	18 673	15 791	55 826
	Kerosene	1 745	160 749	140 614	134 491	143 073	580 673
	Petrol	306 920	238 017	271 500	250 251	226 238	1 292 926
SUBTOTAL		308 665	400 414	431 828	403 415	385 102	1 929 424
PL 66	Diesel	380 508	289 596	224 909	221 216	220 757	1 336 986
	Kerosene	1 431	2 127	4 711	13 452	8 213	29 933
	Petrol	35 689	64 087	36 168	32 261	40 887	209 092
SUBTOTAL		417 627	355 810	265 787	266 930	269 857	1 576 012
TOTAL		726 292	756 224	697 615	670 345	654 959	3 505 436

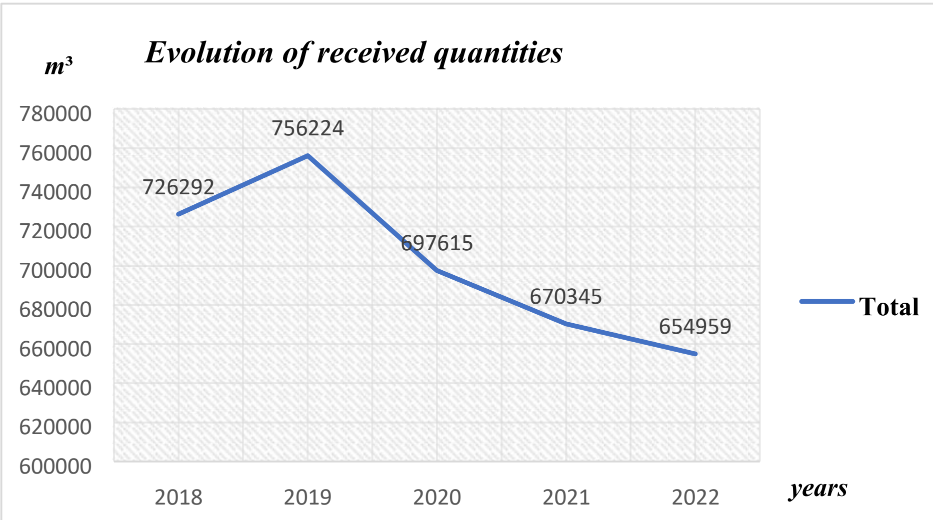


Figure 3*. Evolution of the total quantities curve for all products received from 2018 to 2022 via PL-46 & PL-66.*

The observation remains the same from 2018 to 2022, the volume received continues to increase, except for other years which are characterised by a decrease in the products received due to the informal sectors and multiple causes that we have listed previous in the paper.

Romanian Journal of Petroleum & Gas Technology
Vol. VII (LXXVIII) • No. 1/2026

***Table 4**. Total volume in m³ received per product of PL-46 and PL-66.*

Products	2018	2019	2020	2021	2022	TOTAL
Diesel	380 508	291 244	244 622	239 890	236 548	1 392 812
Kerosene	3 176	162 876	145 325	147 943	151 286	610 606
Petrol	342 609	302 103	307 668	282 513	267 125	1 502 018
TOTAL	726 292	756 224	697 615	670 345	654 959 3	505 436

Figure 4 shows all the totals of each product pumped from two pipelines. It is evident that there is a decrease in each product extracted each year. This is due to informal sectors as well as losses in pumped volume. Losses of products in pumped quantity (in m³) via pipelines from 2018 to 2022 is illustrated in the table 5.

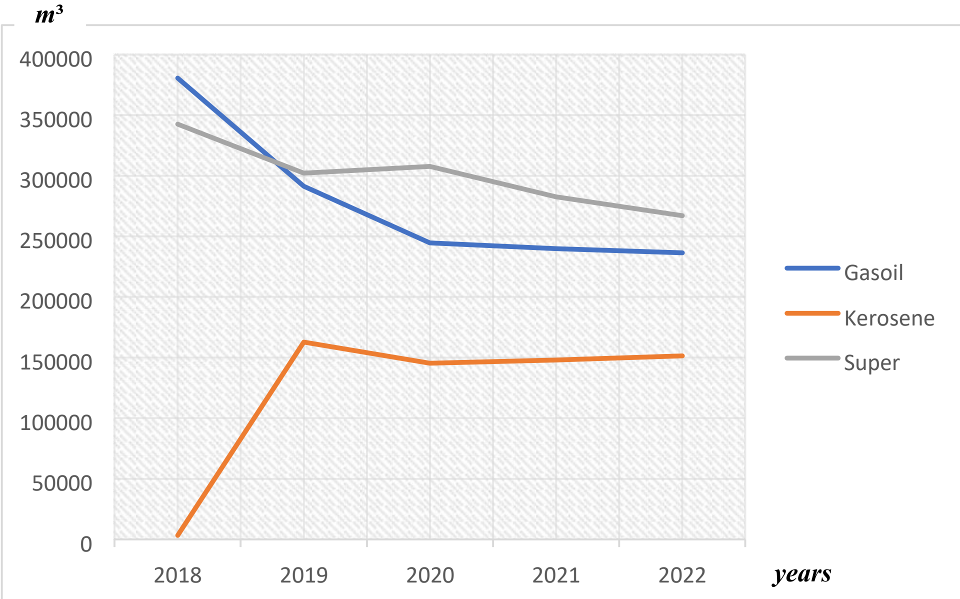


***Figure 4.** Evolution of the total quantities of each product pumped over these five years.*

***Table 5**. Evolution of the quantity of lost products (in m³).*

PL	Products	2018	2019	2020	2021	2022	TOTAL
PL-46	**Diesel**	0,000	0,000	44,288	25,853	52,210	122,351
	Kerosene	10,914	131,521	517,954	322,117	261,597	1 244,103
	Petrol	30,269	47,431	351,641	233,927	293,992	957,260
SUBTOTAL		**41,183**	**178,952**	**913,883**	**581,897**	**607,799**	**2 323,714**
PL-66	**Diesel**	93,348	76,507	1 359,457	734,552	1 083,058	3 346,922
	Kerosene	0,000	0,000	14,371	24,008	22,197	60,576
	Petrol	77,228	14,208	102,219	153,564	210,546	557,765
SUBTOTAL		**170,576**	**90,715**	**1 476,047**	**912,124**	**1 315,801**	**3 965,263**
TOTAL		**211,759**	**269,667**	**2 389,930**	**1 494,021**	**1 923,600**	**6 288,977**
Variance			**57,91**	**2 120,3**	**-895,909**	**429,579**	**1 641,6**

Romanian Journal of Petroleum & Gas Technology
Vol. VII (LXXVIII) • No. 1/2026

It appears from this table that the totals of all discrepancies or losses of pumped products also show a progressive trend over the years. Which still seems obvious given the illustrations in the Figure 5 below.

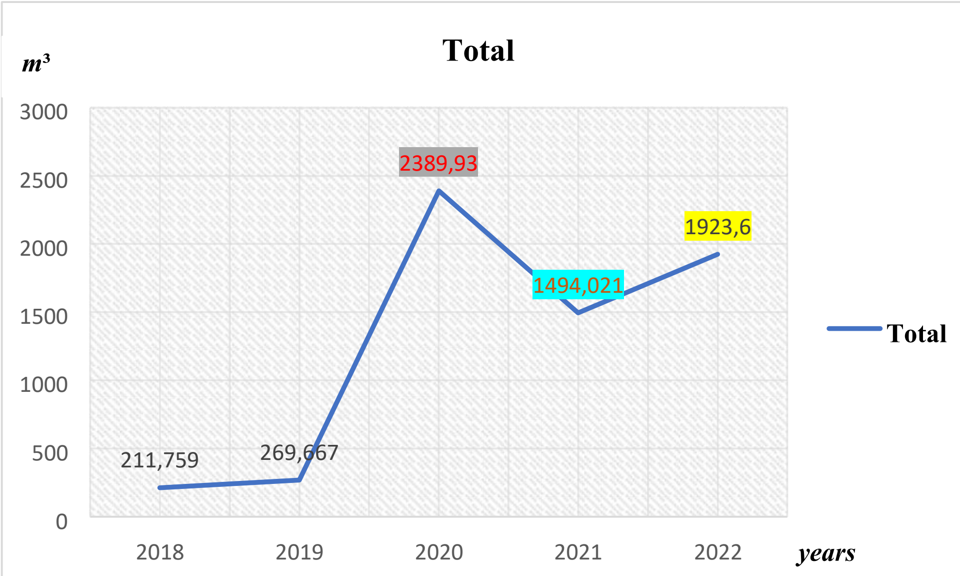


***Figure 5**. Annual total evolution of lost quantities in m³/year.*

We observe during the study period a sharp increase in discrepancies or loss of pumped volume due to various losses from the baseline equipment of 2018 and 2021. Between 2018 and 2020, we observe a negative gap, which explains a clear improvement in the loss gaps for this period as is showed in Table 6.

***Table 6.** Total volume lost in m³ by PL-46 and PL-66 product.*

Products	2018	2019	2020	2021	2022	Total
Diesel	93,3	76,5	1 403,7	760,4	1 135,3	3 469,3
Kerosene/Jet A1	10,9	131,5	532,3	346,1	283,8	1 304,7
Petrol	107,5	61,6	453,9	387,5	504,5	1 515,0
Total	211,8	269,7	2 389,9	1 494,0	1 923,6	6 289,0

Diesel shows a considerable gap, although it is a less volatile product compared to Kerosene and Petrol. This is demonstrated in the graphic illustration in Figure 6.

Figure 6 shows the total losses of each product from two pipelines. It is noted that there is an increase each year in each product produced. This is due to the informal sectors.

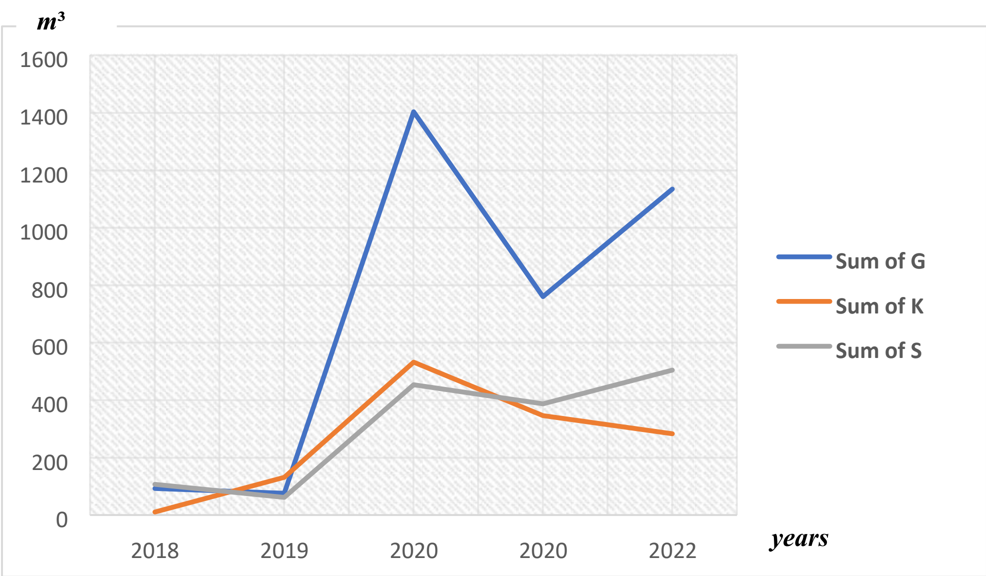


Figure 6. *Evolution of quantity lost per product (m³/year).*

It is clear that the transport loss rate in the pipeline from 2018 to 2022 is concentrated at an average of around 0.21% as is showed in the Table 7. (Note that this rate is the result of the transport loss volume on the pumped quantity).

Therefore, SEP Congo can consider 0.21% as the value of the transport loss assessment index for this pipeline, assuming that the transport volume through the pipeline does not change significantly. Additionally, 0.21% can also be used as the index value for early warnings regarding transfer loss.

Table 7*. Loss rate of major pipelines (in ± %).*

PL	Products	2018	2019	2020	2021	2022	Overall average
PL-46	Diesel	0,000	0,000	0,224	0,138	0,330	0,138
	Kerosene/Jet A1	0,622	0,082	0,367	0,239	0,183	0,298
	Petrol	0,010	0,020	0,129	0,093	0,130	0,076
Average PL46		0,210	0,034	0,240	0,108	0,214	0,171
PL-66	Diesel	0,025	0,026	0,601	0,331	0,488	0,294
	Kerosene/Jet A1	0,000	0,000	0,304	0,178	0,270	0,150
	Petrol	0,216	0,022	0,282	0,474	0,512	0,301
Average PL46		0,080	0,016	0,396	0,328	0,423	0,249
Overall average		0,145	0,025	0,318	0,218	0,319	0,210

By comparing tables 5 and 7, Figure 7 shows that the loss rate between 2017 and 2020 is much higher than the rate in previous years. Therefore, it is necessary to immediately find the reason to determine the source of the loss and take the appropriate measures to control and reduce it.

Romanian Journal of Petroleum & Gas Technology
Vol. VII (LXXVIII) • No. 1/2026

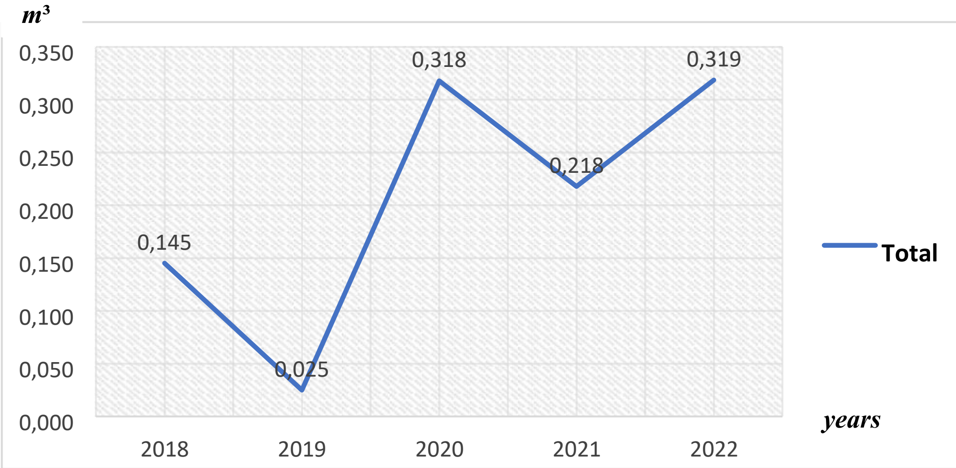


Figure 7. Total loss curve over five years.

Table 8 sheds light on the different threats SEP Congo faced during the transport of products by pipeline during the study period, including: (a) Leak due to a crack: F; (b) Leak due to corrosion: C; and (c) Leak due to a tear: D. A evolution of observed types of leaks during 2018-2022 is shown in Figure 8. We note that SEP Congo experienced fewer leaks during the first two years of our study and many during the remaining years despite a downward trend. This could be explained by an increase in the quantity lost (see table 5) from 2019 to 2022.

Table 8. *Number of leak cases related to observed causes of losses*

	2018			2019			2020			2021			2022		
PL	F	C	D	F	C	D	F	C	D	F	C	D	F	C	D
PL-46	3		1	4	10	2	6	9		7	1		6	5	
PL-66	8	3		3	3		13	6		9	6	1	9	2	
TOTAL	11	3	1	7	13	2	19	15		16	7	1	15	7	

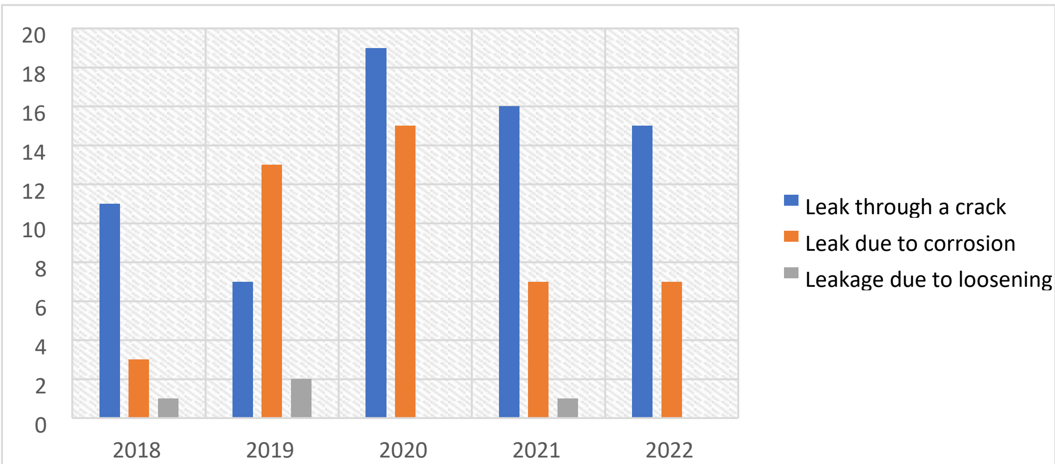


Figure 8*. Evolution of observed types of leaks.*

Romanian Journal of Petroleum & Gas Technology
Vol. VII (LXXVIII) • No. 1/2026

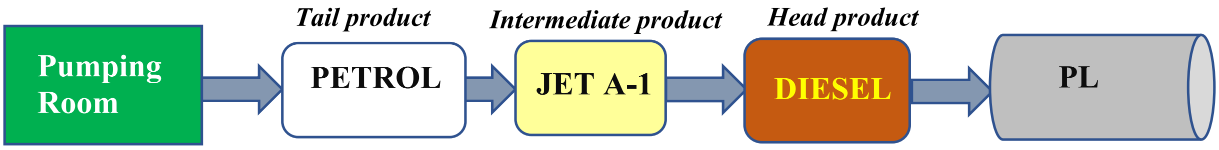
Table 9. Total contaminant volume from 2018 to 2022.

Years	2018	2019	2020	2021	2022	Total
Contaminants	47 064,12	55 088,07	46 893,28	52 186,46	50 404,98	251 636,91
%	18,7	21,9	18,6	20,7	20,0	100

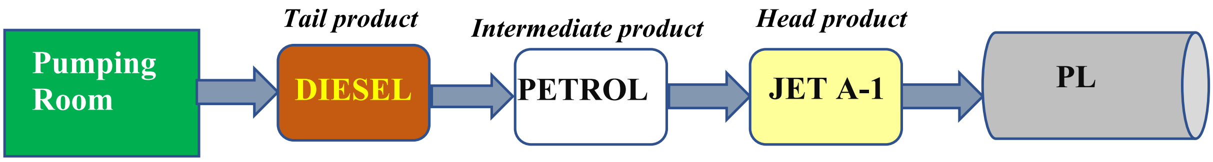
The PL-46 and PL-66 pipelines being multi-product with the sequence Petrol→Jet A-1→Diesel→Jet A-1→Petrol, the share of "inherent/inevitable" contaminants (Table 9) is always in Jet A-1→Petrol or Jet A-1→Diesel.

Due to the delicacy of reception operations and the requirements for preserving product quality, SEP-Congo respects the pumping order of petroleum products as follows:

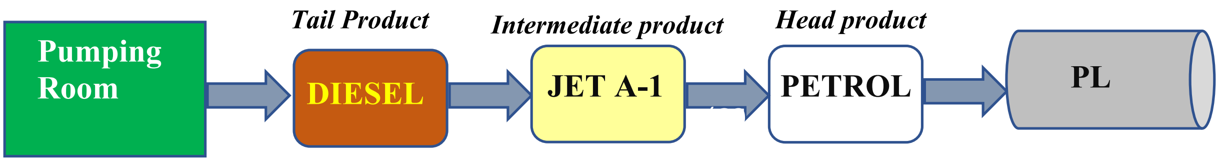
1) For the diesel injection, we proceed:



2) For the injection of Jet A-1, we proceed:



3) For the injection of Super or petrol, proceeds as follows:



This head and tail product arrangement considers the density and viscosity of each product placed in the PL to ensure safety during product pumping to prevent the risk of mixing between two products in case of contamination. The density limits for each type of product are as follows at 15°C:

– High-octane fuel: 725.0 - 790.0 kg/m³;
– Jet A-1: 790.0 - 820.0 kg/m³;
– Diesel: 820.0 - 880.0 kg/m³.

It can observe that Jet A-1 has a density intermediate between aviation gasoline and diesel. The online introduction of products into the pipeline follows this sequence to avoid significant mixing of one product with another due to a large difference in density, which would increase the volume of contamination in the pipeline.

Romanian Journal of Petroleum & Gas Technology
Vol. VII (LXXVIII) • No. 1/2026

CONCLUSIONS

All sectors of activity in a country like the Democratic Republic of Congo need energy to operate to contribute to economic growth and the improvement of the population's social life. The increase in supply volume also depends on infrastructure factors of oil refining, transport and storage activities. As we can see, reducing losses has become the main concern of all companies. Transport and storage are among the processes that frequently generate considerable losses.

This study highlights that losses and spills of petroleum products during transport and storage represent a major economic and environmental issue. Analyses show that physical losses related to evaporation, leaks from cracks, corrosion, loosening, cross-contamination between batches, and filling can account for 0.5 to 2% of transported volumes, while economic losses associated with product downgrading and operational interruptions can result in high annual costs for oil operators. In multi-product pipelines, contaminant management can use up to 1 to 3% of the total transported volume, requiring temporary storage and downgrading to less valuable products. Furthermore, accidental spills significantly contribute to soil and water pollution, increasing health risks and cleanup costs.

These results highlight the need to strengthen maintenance programs, continuous pipeline monitoring and the use of analytical tools such as FMEA and statistical analysis, to sustainably reduce losses, improve logistical performance and limit the environmental impacts of transporting petroleum products.

Nomenclature and abbreviations

API: American Petroleum Institute	km: Kilometre	m^3: Cubic metre
Ango-Ango–Kinshasa Pipeline: transport base or infrastructure for petroleum products linking the Ango-Ango oil terminal to the city of Kinshasa.	L: Litre PL-46: 46 km pipeline section	PL: Pipeline PL-66: 66 km pipeline section
C: Leak due to a tear; D: Leak due to corrosion;	SEP Congo: Congo Petroleum Companies Service	
F: Leak due to a crack	%: Percentage	

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Romanian Journal of Petroleum & Gas Technology
Vol. VII (LXXVIII) • No. 1/2026

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