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Improving the Reliability of Equipment and Facilities for the Rail Tank Wagon Receiving Process Through Modifications to the SUSI (Support System Direct Dry Coupler) to Achieve Low-Emission Operations and Resource Efficiency

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Abstract
This study evaluates the effectiveness of the Support System Direct Dry Coupler (SUSI) as a modification of the Direct Dry Coupler (DDC) system in improving Rail Tank Wagon (RTW) receiving process reliability while reducing environmental impact through pollution prevention and eco-innovation approaches. A before-and-after comparative study design was employed, comparing operational conditions prior to and following SUSI implementation at PT Pertamina Patra Niaga Fuel Terminal Tegal. Parameters analyzed included connect/disconnect process time, discharge loss, VOC emission reduction using the IOGP Tier-1 method, A332-1 hazardous waste generation reduction, housekeeping water-use efficiency, and wastewater quality based on pH, oil and grease, and Total Organic Carbon (TOC) levels. Results demonstrate that SUSI implementation reduced connect/disconnect time from 45–90 minutes to 5–10 minutes while eliminating fuel spillage potential at 78 connection points, yielding a total spill reduction of 142,350 L/year. VOC emission reduction potential reached 6.77×10^{-5} tons of VOC/year based on the IOGP Tier-1 method. Reduced hydrocarbon influx into drainage systems decreased A332-1 oil sludge formation potential, improved wastewater quality with TOC concentration <3 mg/L, and reduced water demand for RTW area housekeeping from 25 kL/year to 5 kL/year, achieving an 80% water-use savings rate. Beyond improvements in operational reliability and occupational safety, this study demonstrates that spill-prevention-based connection system modifications provide simultaneous environmental benefits through air emission reduction, hazardous waste reduction, water-use efficiency, and reduced water pollution load.

INTRODUCTION

The oil and gas industry is one of the strategic sectors supporting global energy security, but it is also a contributor to various environmental impacts, such as greenhouse gas and air pollutant emissions, hazardous waste formation, water pollution, and high consumption of natural resources throughout the petroleum product distribution chain (International Energy Agency [IEA], 2023; United Nations Environment Programme [UNEP], 2017). In the downstream oil and gas sector, product receiving, storage, and distribution activities are stages with high potential for hydrocarbon losses due to fluid transfer processes (loading and unloading), equipment leaks, and evaporation from exposed hydrocarbon surfaces (U.S. EPA, 2020; European Environment Agency [EEA], 2019). The loss of these hydrocarbons not only causes economic losses but also serves as a primary source of Volatile Organic Compound (VOC) emissions, oily waste formation, and increased water pollution burden at fuel terminal facilities (Simayi et al., 2021).

The process of transferring hydrocarbons through a manifold system is one of the most critical operational stages because it involves a series of piping, valves, hoses, and mechanical connections (couplings) operating under pressure (Ghaisas, 2025; Golwalkar & Kumar, 2022; Hadzihafizovic, 2024; Isaac & Sylvanus, 2022). Sealing integrity is the primary factor in preventing product loss during the connection and disconnection process (Taheri et al., 2023; Xiong et al., 2025; Yuan et al., 2024). Leaks at the connection point and residual fluid remaining in the hose can produce fugitive emissions through the evaporation of light hydrocarbons when the liquid comes into direct contact with the atmosphere (U.S. EPA, 2020; API, 2021). Scientifically, the evaporation rate is influenced by the surface area of the liquid, hydrocarbon vapor pressure, temperature, and mass transfer coefficient; thus, the greater the volume of spilled hydrocarbons, the greater the potential VOC emissions generated (API, 2021).

In addition to affecting air quality, hydrocarbons not captured by the recovery system will enter the drainage network to the oil catcher, increasing oil and grease content and Total Organic Carbon (TOC), and accelerating the formation of oily sludge that requires management as *B3* (hazardous and toxic) waste according to its characteristics. The accumulation of hydrocarbon residues in oil catchers also increases the frequency of drainage cleaning, waste management costs, and the risk of environmental pollution if not properly managed (Arghiropol et al., 2025; Etim et al., 2026; Kumar et al., 2025; Lehmann et al., 2026; Yadav et al., 2026). On the other hand, hydrocarbon spills in the operating area require housekeeping activities using clean water, thereby increasing operational water consumption and producing oily wastewater that must be treated before release into the environment (IFC, 2007).

Various technologies have been developed to improve the safety and reliability of the hydrocarbon transfer process, such as dry disconnect couplings, breakaway couplings, quick-connect couplings, and vapor recovery systems. These technologies generally focus on improving the mechanical integrity of the connection and preventing leakage during the loading and unloading process (API RP 1004, 2020; CCPS, 2019; ISO 14420-6:2017). Sha et al. (2022) reported that the reduction of VOC emissions in the petroleum processing industry is greatly influenced by the control of equipment leaks, improvement of sealing system quality, reduction of storage tank emissions, and control of loading and unloading operations. However, most studies still evaluate the mechanical and safety aspects of the process separately, while studies integrating the effect of connection system modifications on the reduction of VOC emissions, *B3* waste generation, water pollution burden, water-use efficiency, and discharge loss at fuel receiving facilities remain very limited.

Conceptually, the reduction of hydrocarbon losses represents the implementation of the pollution prevention at source principle, which aims to prevent pollutant formation at the source before it enters environmental media. This approach is more effective than end-of-pipe treatment because it can simultaneously reduce air emissions, waste formation, and water pollution while increasing resource-use efficiency. Therefore, modification of the connection system capable of eliminating the source of hydrocarbon loss is expected to provide broader environmental benefits beyond simply improving operational efficiency.

PT Pertamina Patra Niaga Fuel Terminal Tegal is one of the fuel distribution terminals that still receives products via the Rail Tank Wagon (RTW) mode. Prior to this study, the hose connection and disconnection process used a conventional connection system consisting of a blank flange, reducer, bolts, gaskets, and grease installed manually. This configuration takes approximately 1–1.5 hours per receiving process, involves a less ergonomic working position, and produces a potential fuel spill of approximately 5 liters per tank wagon at the time of connection or disconnection. This condition caused the discharge loss value to reach −0.12% (YTD October 2024), higher than the company's target of −0.04%, while increasing the potential for VOC emissions, oily sludge formation in oil catchers, water demand for housekeeping activities, and wastewater pollution burden.

Based on these problems, the Support System Direct Dry Coupler (SUSI) was developed as a modification of the Direct Dry Coupler (DDC) system, integrating a quick-locking mechanism, integrated sealing, guiding structure, and drain recovery system. This system allows the connection process to be carried out without the use of blank flanges, reducers, bolts, grease, or separate gaskets, producing a more leak-tight connection, accelerating the connection/disconnection process, and returning residual hydrocarbons in the hose to the system before the connection is removed. Thus, hydrocarbon losses can be minimized at the source, so that the potential for VOC emissions, *B3* waste formation, water consumption for area housekeeping, and water pollution load can be simultaneously suppressed.

The novelty of this research lies in the development and evaluation of the Support System Direct Dry Coupler (SUSI) as a spill prevention technology, evaluated using an eco-innovation approach based on five environmentally integrated indicators, namely: (1) reduction of discharge loss, (2) reduction of VOC emissions using the Tier-1 method of the International Association of Oil & Gas Producers (IOGP), (3) reduction of *B3* waste formation, (4) savings in water use for housekeeping activities, and (5) reduction of water pollution burden based on TOC, oil and grease, and pH parameters. In contrast to previous studies that generally evaluated only the mechanical performance of connection systems, this study demonstrates a cause-and-effect relationship between the reduction of hydrocarbon spills at the transfer point and the improvement of environmental performance through the principles of pollution prevention at source and resource efficiency. This approach results in a comprehensive evaluation framework with the potential to be replicated at fuel receiving facilities with similar operating characteristics.

METHOD

This study used the Applied Engineering Research approach with the before after comparative analysis method to evaluate the effect of the modification of Support System Direct Dry Coupler (SUSI) on increasing the reliability of the Fuel Oil (BBM) receiving process through Rail Tank Wagon (RTW) and its impact on reducing VOC emissions, reducing B3 waste generation, saving water use, and reducing the burden of water pollution. The before-after approach is used to compare operational conditions before and after the implementation of the innovation so that the changes that occur can be attributed to the implementation of the SUSI system (Montgomery, 2019; ISO 14040, 2006).

The research was carried out at the RTW reception facility of PT Pertamina Patra Niaga Fuel Terminal Tegal by comparing baseline conditions using a conventional connection system (blank flange - reducer) to conditions after the implementation of SUSI. Evaluation was carried out on operational and environmental parameters which included connect/disconnect time, discharge loss, fuel splatter volume, VOC emissions, B3 waste generation, water use, and wastewater quality.

A. Research Stage

1. Problem Identification

   The initial stage of the research was carried out using **Root Cause Analysis (RCA)** with **the Fishbone Diagram** method to identify the factors that cause high discharge loss, fuel spillage, VOC emissions, oil sludge formation, high use of housekeeping water, and less ergonomic working conditions in the RTW acceptance process.

   The analysis was carried out using **the 6M** approach, namely **Man, Machine, Method, Material, Measurement**, and **Environment** (Ishikawa, 1986). The causative factors are then prioritized based on the frequency of incidents, the level of risk to operational safety, the magnitude of product loss, and the impact on the environment.

   Data was obtained through field observations, operator interviews, evaluation of Standard Operating Procedures (SOP), discharge loss data, **Management Walkthrough (MWT) reports**, history of fuel receipt activities, and facility inspection documents.

2. SUSI Design and Implementation

   Based on the results of RCA, the development of **a Support System Direct Dry Coupler (SUSI)** was carried out as a modification of the conventional connection system.

   The stages of development include:

   1. **Engineering design**, including identification of operational needs, calculation of connection dimensions, and support frame design.
   2. **Mechanical fabrication**, including the manufacturing process of SUI components.
   3. **Installation**, which is the installation of SUSI at the RTW reception facility.
   4. **Trial and error**, to evaluate the compatibility of the system with the RTW manifold and the existing hose.
   5. **Commissioning**, which is testing the function of the system before it is fully operational.
   6. **Performance verification**, which is the evaluation of the reliability of the system during normal operation.

   SUSI integrates **a quick locking mechanism**, **integrated double sealing**, **guiding structure**, **support frame**, and **drain recovery valve** so that the connect/disconnect process can be carried out without the use of blank flange, reducer, bolts, grease, or separate gaskets. This configuration results in a more leak-tight connection, improves operator ergonomics, speeds up the connection process, and minimizes hydrocarbon release during the connection disconnection process (API RP 1004, 2020; ISO 14420-6:2017; CCPS, 2019).

3. Data Collection

   Data collection was carried out under normal operating conditions before and after the implementation of SUSI with product characteristics, receiving capacity, and comparable number of RTWs:

Table 1.

Parameter	Method
Connect/disconnect time	Stopwatch
Discharge loss	BBM inventor data
Fuel spill volume	Field measurements
Use of water housekeeping	Measurement of the volume of filled water in the PMK car
Timbulan Sludge (A332-1)	Waste Logbook B3
Quality Oil Catcher	Analysis of KAN accredited laboratories

All data is obtained from the company's official operational documents so that it can be traceable and verified.

4. Emissions Analysis Volatile Organic Compounds (VOC)

VOC emission estimation is carried out using **the Tier-1** method based on **the Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Gas Industry** published by the **International Association of Oil & Gas Producers (IOGP)** together with **the American Petroleum Institute (API)** (IOGP, 2020; API, 2021). In contrast to the study that calculates emissions during the connect/disconnect process, this study identifies that the main source of VOC emissions comes from **the evaporation of hydrocarbons contained in open containers** due to fuel spills during the RTW acceptance process.

Although the reservoir is not an **External Floating Roof Tank**, the mechanism for forming its emissions has a similar characteristic, namely the evaporation of hydrocarbons from the surface of liquids directly exposed to the atmosphere. Therefore, **the Tier-1 emission factor of the Hydrocarbon Storage – External Floating Roof Tanks category** is used as a conservative approach to estimate the magnitude of VOC emissions from hydrocarbons contained on the surface of open liquids.

The magnitude of emissions is calculated using the Equation:

$$E = AD \times EF$$

Where:

- **E** = VOC emissions (tons/year)
- **AD** = mass of hydrocarbons stored in the reservoir (tons/year)
- **EF** = Tier-1 emission factor (tons of VOCs/tons of hydrocarbons)

5. Analysis of B3 Waste Generation

Waste generation analysis was carried out using **a mass balance approach** to the flow of hydrocarbon scatterings.

In a conventional system, hydrocarbons that are not accommodated in the reservoir temporarily flow into the drainage system and then enter the **Oil Catcher**. In the Oil Catcher, hydrocarbons are mixed with sediments and suspended solids so that they gradually form **oil sludge** which is categorized as Waste B3 code **A332-1** according to the **Minister of Environment and Forestry Regulation Number 6 of 2021**.

The implementation of SUSI lowers the volume of spit at the source thereby reducing the mass of hydrocarbons entering the Oil Catcher. The reduction in the hydrocarbon load reduces the rate of sludge formation and ultimately reduces the generation of B3 waste.

The amount of waste generation was obtained based on the manifest data of B3 waste transportation from licensed waste managers.

6. Water Usage Analysis

The water use analysis was carried out to evaluate the effect of the implementation of **the Support System Direct Dry Coupler (SUSI)** on the reduction of water demand in the housekeeping activities of the Rail Tank Wagon (RTW) **area**. Prior to the implementation of SUSI, fuel spills that occurred during the connect and disconnect hose process caused the RTW area to be cleaned regularly using water from the **Fire Water Tank**. The water is filled into **the Fire Department**'s car, then used as a medium to clean the operating area to remove hydrocarbon residues on the receiving floor.

After the implementation of SUSI, the volume of fuel spills in the RTW area decreased significantly so that the need for water for housekeeping activities was also reduced. Therefore, the evaluation of water use is carried out based on **the volume of water filled into the PMK car** in each cleaning activity. This approach was chosen because all housekeeping activities in the RTW area are carried out using water supply from PMK cars, so that the filling volume of PMK cars can be used as **a direct indicator (surrogate measurement)** of actual water consumption in cleaning activities. The use of this operational data provides a more accurate representation of water needs than estimates based on washing time, because the recorded volume of water is the amount of water that is actually prepared and used in each housekeeping activity (ISO 46001:2019).

Total water usage is calculated using the following equation:

$$W = \sum_{i=1}^{n} V_i$$

with:

- **W** = total water use for housekeeping activities (m³/year);
- V_i= volume of water filled to the PMK car in each cleaning activity (m³);
- **n** = the number of PMK car charging activities during the observation period.

7. Water Quality Analysis

The water quality evaluation is carried out based on **the Oil Catcher wastewater test result certificate** issued by **the KAN accredited testing laboratory.**

The analyzed parameters include:

- pH
- Oil and Grease
- Total Organic Carbon (TOC)

The **Oil and Grease** parameter is used as the main indicator of the presence of hydrocarbons in wastewater, while **the TOC** is used to describe the total content of organic compounds that have the potential to come from hydrocarbon residues. pH parameters are analyzed to ensure that the characteristics of wastewater still meet applicable quality standards.

RESULTS AND DISCUSSION

Improved RTW Receiving System Reliability through Support System Direct Dry Coupler (SUSI) Modification

The implementation of **the Support System Direct Dry Coupler (SUSI)** significantly improves the reliability of the fuel receiving process through **the Rail Tank Wagon (RTW)** by eliminating potential leak points at conventional connections. Prior to implementation, the hose connection process still used **blank flange**, **reducers**, bolts, gaskets, and grease, so it required a gradual alignment and bolt tightening process to obtain a tight connection. This configuration increases the chance of leaks due to imperfect gasket installation, material deformation due to repeated use, and residual product left in the hose after the transfer process is complete. This condition also causes the **connect/disconnect time** to reach **45–90 minutes** and increases the operator's exposure to hydrocarbons during the loading and unloading process (API RP 1004, 2020).

The SUSI modification replaces the system with **a Direct Dry Coupler (DDC)** which has been modified using **a quick locking**, **integrated sealing**, and **support frame** system so that the connection can be made without the use of blank flange, reducer, grease, or external gaskets. In addition to producing better sealing, this system also reduces **the dead volume** at the connection and is equipped with a **drain recovery mechanism** so that the remaining fuel in the hose can be returned to the system before the connection removal process is carried out. These improvements are able to speed up **the connect/disconnect** time to **5–10 minutes**, improve the reliability of the receiving process, and reduce the potential for product loss due to splatter.

Implementation was carried out at **78 Direct Dry Coupler connection points** used in the RTW acceptance process. Before the program was implemented, the potential for fuel splatter reached around **5 liters for each kettle car** in each receiving activity. After all connections were modified using SUSI, the total fuel spillage that was successfully prevented reached **142,350 liters per year**. The reduction in product loss shows that the modification of the connection system is able to control the source of pollution directly (source reduction) so that various environmental impacts can be prevented before entering the environmental media.

The Effect of SUSI Implementation on VOC Emission Reduction

One of the environmental impacts that has been successfully suppressed through the implementation of SUSI is the reduction of **Volatile Organic Compounds (VOC) emissions**. In pre-implementation conditions, fuel splatters that are not accommodated in the spill tray will flow into the drainage system and eventually enter the **Oil Catcher**. Hydrocarbons on the surface of the open tub undergo an evaporation process due to product vapor pressure, ambient temperature, wind speed, and direct contact with the atmosphere. The evaporation process is one of the sources of **fugitive VOC emissions** at fuel storage and distribution terminals (API, 2021; U.S. EPA AP-42, Chapter 7.1).

Emission estimation was carried out using **the IOGP Tier 1** approach in **the category of Hydrocarbon Storage – External Floating Roof Tank** as a conservative approach to represent the evaporation of hydrocarbons from the liquid surface in an open reservoir. Based on the volume of fuel splatters that have been successfully reduced by **142,350 liters/year**, with a density conversion factor **of 0.000709900443561795 tons/liter**, a hydrocarbon mass of **101.05 tons/year** was obtained. By using an emission factor **of 8.5 × 10^{-7} tons of VOC/ton of**

hydrocarbons, the potential emission reduction of **6.77×10^{-5} tons of VOC/year** or around **67.7 grams of VOC per year** is obtained.

Although the mass value of VOC emissions appears to be relatively small, these results show the success of implementing **pollution prevention strategies**, which are preventing emissions from forming from the source, rather than controlling emissions after they are released into the atmosphere. Emission reductions through process equipment modifications are generally more sustainable than the application of end-of-pipe control technology, as they do not require additional energy or produce secondary waste (U.S. EPA, 1992; OECD, 2009).

Reduction of B3 Waste Generation Code A332-1

The implementation of SUSI also has an impact on reducing the formation of **oil sludge** classified as **Waste B3 code A332-1**. In the previous system, the fuel splatters that flow through the drainage to the Oil Catcher are mixed with sediments and solids so that they gradually form oily sludge that must be managed as B3 waste.

In **December 2025**, the Oil Catcher will be drained and 0.234 tons of sludge will be produced. The resulting sludge **is not sludge formed during 2025 only**, but is an **accumulation of sediment since the Tegal Fuel Terminal began operating (commissioning) in 2020**. Thus, the depleted sludge mass cannot be used directly to evaluate the effectiveness of SUSI within one year of implementation.

However, the implementation of SUSI has reduced the volume of fuel splatters entering the drainage system by **142,350 liters/year**, so that the hydrocarbon load process mechanism that has the potential to form sludge in the Oil Catcher has also decreased significantly. With the reduction of the accumulation of hydrocarbons, the rate of sludge formation in the next period of operation is expected to be lower than the conditions before implementation. This phenomenon shows that the main benefit of SUSI lies in **preventing the formation of waste at the source (source reduction),** not just reducing the volume of waste that has been formed.

Reduced Water Use

The reduction of fuel spills also has a direct impact on reducing water demand for housekeeping activities in the RTW area. Prior to the implementation of SUSI, the reception area must be cleaned using **1 PMK car with a capacity of 5 kL** every **2-3 months** due to the high fuel spillage on the operating floor. Assuming an average frequency **of 5 times per year**, then the water requirement reaches around:

$$5 \text{ kegiatan/tahun} \times 5 \text{ kL} = 25 \text{ kL/tahun}$$

After the implementation of SUSI, the need for area cleaning is reduced to **1 time per year**, so that water consumption becomes:

$$1 \times 5 = 5 \text{ kL/tahun}$$

Thus, the implementation of SUSI is able to save water use by the following amounts:

$$25 - 5 = 20 \text{ kL/tahun}$$

or equivalent to **an 80% reduction in water use** for housekeeping activities in the RTW area.

This reduction shows that controlling fuel spills at the source not only reduces product loss, but also reduces the need for operational support resources, thereby increasing **the efficiency of water use** according to the principle **of resource efficiency** (ISO 46001:2019).

Water Quality Improvement

The decrease in fuel spills has a positive impact on water quality in Oil Catcher. The results of laboratory analysis showed that **the concentration of Total Organic Carbon (TOC)** after the implementation of SUSI **tended to decrease to less than 3 mg/L**, far below the **quality standard of 110 mg/L** used as the company's operational reference. The decrease in TOC shows a reduction in the content of organic compounds derived from hydrocarbons in wastewater due to the reduction of fuel spills entering the drainage system.

Oil **and Grease** parameters and **pH** remain within the normal range so that wastewater characteristics remain stable. These results show that SUSI modifications not only reduce product loss, but are also able to reduce the burden of water pollution through the reduction of hydrocarbon contamination sources. These findings are in line with the principle **of Best Available Techniques (BAT)** which emphasizes pollution control from the process stage as a more effective approach than increasing the capacity of waste treatment units.

CONCLUSION

This study shows that the implementation of Support System Direct Dry Coupler (SUSI) in the process of receiving Fuel Oil (BBM) through Rail Tank Wagon (RTW) has succeeded in increasing operational reliability while providing significant environmental benefits through the spill prevention at source approach. Modifying the conventional connection system into a system that integrates a quick locking mechanism, integrated sealing, guiding structure, and drain recovery can significantly reduce the potential for fuel spills, thereby improving operational efficiency and reducing environmental impact on various media. The implementation of SUSI succeeded in reducing the potential for fuel spillage by 142,350 liters/year, which directly reduced the potential for Volatile Organic Compounds (VOC) emissions by 6.77×10^{-5} tons of VOC/year based on the IOGP Tier-1 approach. The reduction of hydrocarbons entering the drainage system also reduces the potential for oil sludge formation as B3 Waste code A332-1, although the sludge transported in 2025 of 0.234 tons is an accumulation of residue formed since the facility operates and not solely the result of formation during the SUSI's implementation period. In addition, the frequency of housekeeping activities in the RTW area decreases from every 2–3 months to once per year, resulting in water use savings of around 15 m^3/year. The improvement was also followed by a reduction in the water pollution burden in the Oil Catcher, which was shown by the concentration of Total Organic Carbon (TOC) which was in the range of <3 mg/L, remaining below 5 mg/L, as well as the oil and fat parameters and pH that met the quality standards. The results of this study confirm that simple modifications to the fuel receipt connection system are able to provide wider benefits than improving the mechanical aspect alone. The developed approach not only improves the reliability of the receiving process and reduces discharge loss, but also integrates aspects of air emission reduction, B3 waste formation, water consumption, and water pollution load in a single engineering solution. Thus, the Support System Direct Dry Coupler (SUSI) can be categorized as an eco-innovation that applies the principles of pollution prevention at source and resource efficiency, and has high potential to be replicated in other fuel receiving facilities that use a hydrocarbon transfer system through a Rail Tank Wagon or similar modes of transportation. In addition to making a practical contribution to improving the operational performance of fuel terminals, this study also enriches the study on the application of process engineering as an environmental impact mitigation strategy in the downstream oil and gas sector.

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