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Integrated Technical, Thermal, and Techno-Economic Assessment of Hot-Oil and Electric Heating Systems for 15–22 MT Asphalt Storage Tanks

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Abstract: The selection of an appropriate heating system for asphalt storage tanks plays a critical role in determining operational efficiency, maintenance requirements, energy consumption, and long-term investment performance in asphalt production facilities. Conventional hot-oil heating systems have been widely implemented because of their ability to provide uniform heat distribution; however, they require complex auxiliary equipment, continuous fuel consumption, and intensive maintenance. Consequently, evaluating alternative heating technologies has become increasingly important for improving industrial efficiency and reducing operating costs. **Objective:** This study aims to compare the technical design, thermal performance, and economic performance of hot-oil and electric heating systems for asphalt storage tanks with capacities ranging from 15 to 22 MT in order to identify the most suitable engineering solution for medium-capacity applications. **Methodology:** This research employed a quantitative comparative engineering approach using validated secondary engineering data, industrial equipment specifications, and operating-cost assumptions. The analysis included comparisons of technical design characteristics, initial investment, annual operating costs, payback period, ten-year life-cycle cost, and thermal-performance indicators under identical operating conditions. **Findings:** The results indicate that the electric-heating system provides a simpler engineering configuration, shorter installation time, lower maintenance requirements, and higher temperature-control accuracy than the hot-oil system. Economically, the electric-heating system reduces annual operating costs by approximately IDR 661.34 million, achieves a simple payback period of approximately 0.38 years (4.5 months), and lowers the ten-year life-cycle cost by approximately IDR 6.86 billion. Furthermore, the electric-heating system maintains nearly 100% point-of-use thermal efficiency, whereas the efficiency of the hot-oil system decreases over time because of combustion losses and equipment ageing. **Implications:** The findings provide practical engineering guidance for selecting heating systems in asphalt storage facilities by demonstrating that electric heating can improve operational efficiency while reducing long-term investment and maintenance costs. The results may also support engineering decision-making related to industrial process electrification. **Originality:** The originality of this study lies in the integration of technical design comparison, thermal-performance evaluation, and comprehensive techno-economic analysis into a unified engineering assessment framework for medium-capacity asphalt storage tanks. This integrated approach provides a practical reference for engineers and decision-makers considering the modernization of industrial asphalt-heating systems.

Keywords: asphalt storage tank; electric heating; hot-oil heating; life-cycle cost; techno-economic analysis.

INTRODUCTION

Bitumen storage and handling require controlled heating because the viscosity and flow behavior of bitumen are strongly dependent on temperature. Bitumen becomes progressively more resistant to pumping and circulation as its temperature decreases, whereas excessive heating may accelerate oxidative ageing, alter rheological properties, increase energy consumption, and elevate occupational exposure to asphalt emissions. The appropriate storage temperature should therefore be determined according to the binder grade and the viscosity required for storage, handling, and pumping rather than treated as a single universal value. General industry guidance recommends storing bitumen at a temperature corresponding to a viscosity of approximately 100 cSt, handling it at approximately 200 cSt, and pumping it at a viscosity not exceeding approximately 500 cSt (Asphalt & Eurobitume, 2024). Experimental research has also demonstrated that alternative temperature-management strategies can reduce storage energy consumption without necessarily producing unacceptable changes in the physical and chemical properties of paving-grade bitumen (Tahri et al., 2021). For medium-capacity asphalt tanks of 15–22 metric tons, inadequate heater sizing, insulation, temperature control, or heat distribution may lead to extended cold-start duration, excessive surface heat loss, temperature stratification, localized overheating, carbon deposition, and unnecessary energy expenditure. In the present case study, a representative 20 MT asphalt tank is assumed to consume approximately 422 kWh of electricity per operating day or approximately 100 L of industrial diesel per day under 8 h of active production and 16 h of temperature-maintenance operation. These case-specific values indicate the need to determine whether the additional burner, thermal-fluid loop, circulation pump, piping system, expansion tank, and intermediate heat-transfer stage of a hot-oil system remain technically and economically justified compared with direct electric heating.

Previous investigations of bitumen storage and industrial process heating can be classified into at least three technical approaches. First, experimental and operational studies have evaluated storage-temperature variation, bitumen ageing, insulation performance, combustion settings, heat losses, and operational energy demand. Tahri found that modified bitumen-storage strategies could significantly reduce energy consumption while maintaining acceptable binder properties (Tahri et al., 2021). More broadly, industrial furnace assessments have identified insulation effectiveness, excess combustion air, flue-gas conditions, furnace-surface temperature, opening duration, and initial material temperature as influential parameters governing process-heating energy requirements (Bisht et al., 2024). Technical guidance from the U.S. Department of Energy, similarly emphasizes that combustion losses, exhaust-gas temperature, wall losses, air leakage, inadequate control, and poorly maintained heat-transfer surfaces can substantially reduce process-heating performance (Energy, 2015, 2016). However, these experimental and operational studies generally do not provide a direct design and economic comparison between hot-oil and electric heating for medium-capacity asphalt tanks.

Second, modelling, simulation, and system-integration studies have investigated industrial heating through heat-balance modelling, computational fluid dynamics, process integration, thermal storage, and demand-side management. Energy-system studies indicate that industrial electrification can improve controllability and reduce direct combustion losses, although its overall performance depends on grid characteristics, process temperature, electricity generation, and plant operating schedules (Munoz-Maldonado et al., 2023). Process-integration research also shows that electrified heating technologies should be evaluated together with heat recovery, thermal storage, and flexible operating strategies rather than as isolated equipment replacements (Lincoln et al., 2022). In a study directly related to bitumen storage, Cook combined computational fluid dynamics and techno-economic analysis to assess the replacement of fuel-fired heaters with electric immersion heaters (Matthew Cook et al., 2025). Their results showed that bitumen tanks can provide thermal flexibility and that variable heating schedules may be implemented without exceeding recognized storage-temperature constraints. Nevertheless, the study was based on a United Kingdom refinery and market framework, so its economic results cannot be transferred directly to Indonesian asphalt plants with different tank capacities, fuel prices, electricity tariffs, and infrastructure conditions.

Third, techno-economic, optimization, and decarbonization studies have compared electric resistance heating, electric boilers, heat pumps, fuel-fired boilers, thermal storage, and other industrial heat technologies. Hasanbeigi and Zuberi demonstrated that the economic feasibility of process-heating electrification varies substantially with electricity prices, fuel costs, operating hours, process configuration, and national energy conditions (Hasanbeigi & Zuberi, 2022). Reviews of industrial electrification also indicate that direct electric heating offers rapid control, modular installation, and the elimination of on-site combustion, but may require electrical-capacity upgrades and can remain economically unattractive where electricity is expensive relative to fossil fuel (International Energy, 2018, 2022, 2023). Recent international assessments further identify electrification, process optimization, insulation improvement, heat recovery, and thermal storage as complementary pathways for improving industrial energy performance (International Energy, 2020, 2025a, 2025b). Although these studies provide an extensive basis for industrial heat electrification, an integrated comparison covering component-level design, initial investment, daily energy consumption, annual maintenance expenditure, simple payback period, thermal efficiency indicators, and ten-year life-cycle cost for 15–22 MT asphalt tanks under Indonesian operating conditions remains limited. This constitutes the engineering research gap addressed by the present study.

This study aims to conduct a comparative engineering assessment of hot-oil and electric-heater systems for a representative 20 MT asphalt storage tank within the 15–22 MT capacity class. The technical objectives are to: (1) compare the system configurations based on the number of primary components, installation-space requirement, safety provisions, operator qualifications, installation duration, and temperature-control capability; (2) calculate the annual energy and maintenance costs under a defined operating schedule of 300 days per year; (3) determine the difference in total annual expenditure between the two heating alternatives; (4) calculate the simple payback period associated with selecting the system with lower initial and operating costs; (5) estimate the ten-year life-cycle cost of each system; and (6) evaluate thermal-performance indicators including point-of-use energy-conversion efficiency, combustion-related losses, radiative losses, cold-start duration, and temperature uniformity. The assessment uses the operational assumptions defined for the investigated tank, manufacturer technical specifications, traceable engineering literature, and Indonesian electricity and industrial-diesel price data.

The technical contribution of this study is an integrated decision framework that combines heating-system architecture, thermal-performance indicators, and life-cycle economics for medium-capacity asphalt storage tanks. Unlike sector-level studies of industrial electrification, the proposed assessment applies the comparison to a defined tank capacity, energy requirement, operating duration, and Indonesian energy-price structure. The engineering hypothesis is that direct electric heating can provide better overall technical and economic performance for 15–22 MT asphalt tanks when a stable and adequately sized electrical connection is available. This anticipated advantage arises from eliminating the burner, combustion-air system, flue-gas pathway, thermal-fluid circulation loop, circulation pump, expansion tank, and intermediate heat-transfer stage required by a hot-oil system. Electric heating is therefore expected to reduce installation complexity, local combustion emissions, maintenance requirements, and total operating expenditure while improving control responsiveness. However, the study does not assume that electric heating is universally superior. The technical selection must also consider grid reliability, available electrical capacity, local electricity-to-fuel price ratios, cold-start requirements, process continuity, and the consequences of an electrical outage. This conditional hypothesis is consistent with international findings that the feasibility of industrial electrification is strongly site-specific and should be established through combined technical and economic evaluation rather than point-of-use efficiency alone (Hasanbeigi & Zuberi, 2022; International Energy, 2023, 2025a).

RESEARCH METHOD

This study adopts a comparative engineering case-study design based on analytical and techno-economic evaluation. The analytical approach was selected because the primary objective is to compare two alternative heating technologies operating under identical boundary conditions without modifying their physical configurations. Engineering calculations were performed using established thermodynamic, heat-transfer, and economic equations commonly applied in industrial heating-system evaluation. The comparative framework enables the technical performance, operational cost, thermal efficiency, and long-term economic feasibility of both systems to be evaluated using the same operating assumptions and engineering parameters. This approach is appropriate for decision-support studies where engineering design alternatives are assessed before implementation.

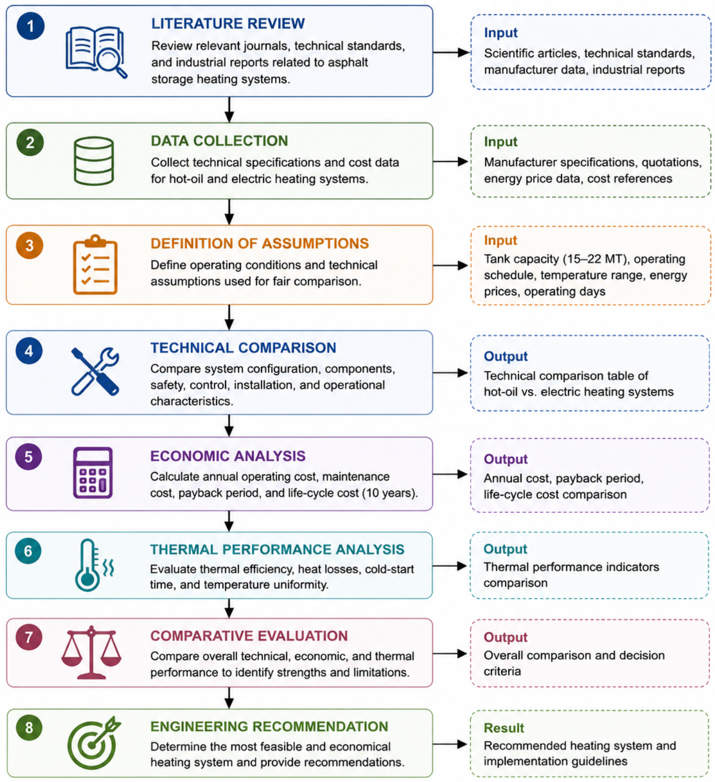

Figure 1. Research Methodology Flowchart

The analysis employs validated secondary engineering data obtained from multiple technical sources. Technical specifications of hot-oil heaters, electric immersion heaters, and supporting equipment were collected from industrial manufacturers and engineering product documentation. Engineering properties, operating temperatures, and heating characteristics were obtained from internationally recognized technical references concerning bitumen storage and industrial process heating. Industrial electricity tariffs and diesel fuel prices were obtained from official Indonesian publications applicable to the 2026 operating period. The engineering calculations further use operational assumptions representing a typical 20 MT asphalt storage tank operating for 300 days per year under 8 h of production and 16 h of temperature-maintenance mode.

The principal engineering parameters considered in this study include installed heating capacity, annual operating duration, annual maintenance cost, initial investment cost, thermal efficiency, fuel consumption, electricity consumption, start-up heating time, heat-loss characteristics, and temperature-control capability.

Data Collection Techniques

Engineering data were collected through technical-document analysis and engineering parameter extraction. Manufacturer specifications were reviewed to identify equipment configuration, heating capacity, installation requirements, control systems, operating temperature limits, and maintenance characteristics for both heating technologies. Engineering parameters describing thermal performance were obtained from published literature and industrial technical documents. Economic parameters, including equipment costs, electricity tariffs, diesel prices, installation costs, and maintenance expenditure, were compiled from supplier information, official industrial energy-price publications, and engineering cost references.

To ensure consistency, all engineering calculations were performed using identical operational assumptions for both heating systems. These assumptions include identical tank capacity, operating schedule, storage temperature range, annual operating days, and maintenance interval. This normalization allows the observed differences in performance to be attributed solely to the heating-system configuration rather than external operating conditions.

Data Analysis Techniques

The collected engineering data were analysed using comparative engineering analysis consisting of technical, thermal, and economic evaluations. The technical evaluation compares system architecture, installation complexity, equipment requirements, safety considerations, control capability, installation duration, and operator requirements. The economic evaluation calculates annual operating cost, annual maintenance cost, simple payback period (PP), and life-cycle cost (LCC). Annual operating cost is calculated using Equation (1) for the electric-heating system and Equation (2) for the hot-oil heating system.

$$[B_{electric} = (P \times t \times H_{electric} \times 300) + M_{electric}]$$

where

(B_{electric}) = annual operating cost (IDR/year)
(P) = installed electrical power (kW)
(t) = daily operating time (h/day)
(H_{electric}) = industrial electricity tariff (IDR/kWh)
(M_{electric}) = annual maintenance cost (IDR/year)

The annual operating cost of the hot-oil heating system is determined by

$$\left[B_{hot-oil} = \left(F \times H_{fuel} \times 300\right) + M_{hot-oil}\right]$$

where

(F) = daily fuel consumption (L/day)
$\left(H_{fuel}\right)$= industrial diesel price (IDR/L)
$(M_{hot-oil})$= annual maintenance cost (IDR/year)
The simple payback period is determined using

$$\left[PP = \frac{I_{hot-oil} - I_{electric}}{B_{hot-oil} - B_{electric}}\right]$$

where (I) represents the initial investment cost.

The long-term economic performance is evaluated using the life-cycle cost equation

$$[LCC = I + N(B + M) + D - R]$$

where (N) denotes service life (years), (D) is disposal cost, and (R) is residual value.

Thermal performance is evaluated using heating-system efficiency. For the electric heating system, point-of-use efficiency is expressed as

$$[\eta_{electric} = \frac{Q_{useful}}{E_{electric}} \times 100$$

For the hot-oil heating system,

$$\frac{\dot{m}c_p\Delta T}{\dot{m}_{fuel}HHV} \times 100$$

The heat-loss rate from the asphalt storage tank is calculated using

$$UA\left(T_{asphalt} - T_{ambient}\right)]$$

where (U) is the overall heat-transfer coefficient, (A) is the external surface area of the tank, $\left(T_{asphalt}\right)$is the asphalt temperature, and $(T_{ambient})$ is the surrounding-air temperature.

Finally, all calculated performance indicators were compared to determine the engineering advantages and limitations of each heating technology under identical operating conditions. The comparative results were subsequently interpreted to identify the most technically feasible and economically advantageous heating system for asphalt storage tanks with capacities between 15 and 22 MT.

RESULT

Technical Design Comparison

A technical comparison was conducted to evaluate the engineering characteristics of the hot-oil and electric-heating systems for asphalt storage tanks with capacities ranging from 15 to 22 MT. The comparison includes system configuration, installation requirements, operating temperature, safety aspects, installation duration, control capability, and operational emissions. The results are presented in Table 1.

Table 1. Technical Comparison between Hot-Oil and Electric Heating Systems

Parameter	Hot-Oil Heating System	Electric Heating System
Main components	Boiler, burner, circulation pump, thermal-oil piping, expansion tank, valves, PLC	Immersion heating element, control panel, thermostat/PLC, contactor
Installation space	4–6 m² (boiler room required)	Installed directly on the tank flange; no additional boiler room required
Operating temperature	200–320°C (up to 350°C)	150–350°C
Safety risk	Fire hazard, hot-oil leakage, flue-gas emission	Electrical short circuit, overheating without dry-run protection
Operator qualification	Certified boiler operator required	General electrical technician
Installation duration	5–7 days	1–2 days
Temperature control accuracy	±3°C	±1°C (PID control)
Local operational emission	CO_2 and NOx emissions	No direct local emissions

Table 1 shows that the electric-heating system requires fewer supporting components because the heating element is installed directly on the tank without requiring a boiler, circulation pump, expansion tank, or thermal-oil piping network. Consequently, the required installation space is smaller and the installation process is shorter, requiring approximately 1–2 days compared with 5–7 days for the hot-oil system.

Regarding operational characteristics, the electric-heating system provides a wider control accuracy of approximately ±1°C using a programmable temperature controller, whereas the hot-oil system achieves approximately ±3°C under normal operating conditions. In contrast, the hot-oil system is capable of producing more uniform heat distribution throughout the asphalt volume due to indirect heat transfer through circulating thermal oil. Operational emissions also differ considerably, with combustion-based hot-oil heating generating exhaust gases, whereas the electric-heating system produces no direct emissions at the point of use.

Economic Performance

Initial Investment

The estimated initial investment for both heating systems was compiled from equipment suppliers and industrial engineering references. The comparison is summarized in Table 2.

Table 2. Estimated Initial Investment Cost

Cost Component	Hot-Oil Heating System (IDR)	Electric Heating System (IDR)
Main heating equipment	150,000,000–350,000,000	40,000,000–120,000,000
Pump and auxiliary equipment	15,000,000–40,000,000	10,000,000–30,000,000
Control panel and automation	10,000,000–30,000,000	20,000,000–50,000,000
Piping, fittings, and insulation	20,000,000–50,000,000	Not required
Installation and commissioning	15,000,000–40,000,000	5,000,000–20,000,000
Estimated total investment	**230,000,000–565,000,000**	**75,000,000–220,000,000**
Average investment	**400,000,000**	**150,000,000**

The estimated total investment for the hot-oil heating system ranges from IDR 230 million to IDR 565 million, with an average investment of approximately IDR 400 million. In comparison, the electric-heating system requires an estimated investment between IDR 75 million and IDR 220 million, with an average value of approximately IDR 150 million. The investment difference mainly originates from additional auxiliary equipment required by the hot-oil system, including the boiler, circulation pump, expansion tank, insulated piping, and burner assembly.

Annual Operating Cost

Annual operating costs were calculated using the electricity tariff and industrial diesel price assumptions described in the methodology section.

For the electric-heating system,

$$[B_{electric} = 148{,}659{,}000 \text{ IDR/year}] Forthehot - oilheatingsystem, [B_{hot-oil} = 810{,}000{,}000 \text{ IDR/year}]$$

The comparison is summarized in Table 3.

Table 3. Annual Operating Cost Comparison

Cost Component	Hot-Oil Heating System (IDR/year)	Electric Heating System (IDR/year)	Difference (IDR/year)
Annual energy cost	750,000,000	141,159,000	608,841,000
Annual maintenance cost	60,000,000	7,500,000	52,500,000
Total annual operating cost	**810,000,000**	**148,659,000**	**661,341,000**

Based on the engineering calculations, annual operating expenditure for the electric-heating system is approximately IDR 148.66 million, whereas the hot-oil system requires approximately IDR 810 million per year. The difference between the two systems reaches approximately IDR 661.34 million annually. Energy expenditure represents the largest component of annual operating cost for both systems.

Payback Period

The simple payback period was calculated using the difference in initial investment and annual operating expenditure between both systems. 0.38 years]or approximately **4.5 months**.

The calculation indicates that the additional investment associated with the hot-oil heating system is equivalent to approximately 0.38 years of annual operating-cost savings obtained from the electric-heating alternative under the assumed operating conditions.

Life-Cycle Cost

The ten-year life-cycle cost (LCC) was calculated using the initial investment and cumulative annual operating costs.

For the electric-heating system indicating a substantially lower cumulative expenditure for the electric-heating system over a ten-year operating period.

Thermal Performance

Thermal performance was evaluated using thermal-conversion efficiency, combustion losses, radiative losses, cold-start duration, and temperature uniformity. The comparison is summarized in Table 4.

Table 4. Thermal Performance Comparison

Parameter	Hot-Oil Heating System	Electric Heating System
Initial investment (IDR)	400,000,000	150,000,000
Total operating cost (10 years) (IDR)	8,100,000,000	1,486,590,000
Life-cycle cost (LCC) (IDR)	**8,500,000,000**	**1,636,590,000**
Cost saving using electric heating (IDR)	colspan →	**6,863,410,000**

The electric-heating system exhibits a point-of-use thermal efficiency of approximately 100% because electrical energy is converted directly into heat within the immersion heater. In contrast, the hot-oil heating system exhibits an initial thermal efficiency of approximately 80–85%, which decreases to approximately 50–65% after seven years of operation without major overhaul. Combustion losses through exhaust gases range from approximately 15–18% for new equipment and may exceed 40% during long-term operation.

Regarding operational performance, the electric-heating system requires approximately 4.5 h to reach operating temperature, whereas the hot-oil system requires approximately 6–8 h. Conversely, the hot-oil system provides better temperature uniformity throughout the asphalt tank because heat is transferred indirectly through continuously circulating thermal oil.

Comparative Engineering Assessment

The overall engineering comparison between both heating technologies is summarized in Table 5.

Table 5. Summary of Comparative Engineering Performance

Performance Indicator	Hot-Oil Heater	Electric Heater
Initial investment	Higher	Lower
Annual operating cost	Higher	Lower
Maintenance requirement	Higher	Lower
Installation complexity	Higher	Lower
Installation time	Longer	Shorter
Thermal efficiency	Lower	Higher
Cold-start duration	Longer	Shorter
Temperature uniformity	Better	Moderate
Local operational emissions	Present	None

Table 5 summarizes the engineering performance obtained from the comparative analysis. The electric-heating system demonstrates lower investment requirements, reduced operating expenditure, shorter installation time, higher point-of-use efficiency, and lower maintenance requirements. Meanwhile, the hot-oil heating system maintains a more uniform temperature distribution throughout the asphalt tank due to indirect heat transfer using circulating thermal oil.

DISCUSSION

The comparative evaluation demonstrates that the engineering architecture of the heating system significantly influences installation complexity, operational requirements, and maintenance activities. The hot-oil heating system requires several auxiliary components, including a combustion burner, thermal-oil boiler, circulation pump, expansion tank, insulated piping network, and safety devices. These additional components increase installation complexity, enlarge the required installation space, and introduce multiple potential failure points throughout the system.

Conversely, the electric-heating system employs a direct immersion-heating configuration in which electrical energy is converted directly into heat within the asphalt tank. Eliminating the intermediate thermal-fluid circulation loop simplifies the overall system architecture and reduces installation requirements. The shorter installation duration reported in this study is therefore consistent with the reduced number of mechanical components required by the electric-heating configuration.

Although the hot-oil system exhibits superior temperature uniformity because thermal energy is distributed continuously through circulating heat-transfer fluid, this engineering advantage becomes less significant for medium-capacity storage tanks (15–22 MT), where thermal gradients are relatively easier to control. Consequently, the simplified architecture of the electric-heating system represents a practical engineering solution for medium-capacity asphalt storage applications.

The economic analysis demonstrates that operating expenditure is the principal factor differentiating both heating technologies. Although both systems perform the same engineering function, their operating mechanisms result in substantially different energy requirements and maintenance costs.

The hot-oil system consumes industrial diesel continuously to maintain combustion while simultaneously operating circulation pumps and supporting equipment.

Consequently, fuel expenditure becomes the dominant operating cost. In contrast, the electric-heating system converts electrical energy directly into heat with minimal auxiliary equipment, reducing both energy losses and maintenance activities.

The annual operating-cost difference of approximately IDR 661 million generated a calculated payback period of only approximately 0.38 years (4.5 months). From an engineering investment perspective, this relatively short payback period indicates that operating-cost savings become the dominant economic consideration compared with the initial investment. Furthermore, the ten-year life-cycle cost analysis demonstrates cumulative savings of approximately IDR 6.86 billion for the electric-heating system under the assumed operating conditions.

These findings are consistent with recent techno-economic assessments of industrial process electrification, which indicate that replacing combustion-based heating with electric heating becomes economically attractive when electricity prices remain relatively stable and fossil-fuel prices continue to increase (M. Cook et al., 2025; Hasanbeigi & Zuberi, 2022). The thermal-performance comparison highlights the influence of energy-conversion mechanisms on heating efficiency. Electric immersion heating converts electrical energy directly into thermal energy at the heating element, eliminating combustion losses, exhaust-gas losses, and thermal losses associated with intermediate heat-transfer media. Consequently, the point-of-use thermal efficiency remains close to 100% throughout the service life of the equipment.

In contrast, the hot-oil system experiences multiple heat-transfer stages, beginning with combustion inside the burner, followed by heat transfer to the thermal oil and finally to the asphalt through the heating coils. Each stage introduces unavoidable thermal losses. In addition, combustion efficiency gradually decreases because of burner deterioration, fouling, soot accumulation, and thermal-fluid degradation. These mechanisms explain the reduction in thermal efficiency from approximately 80–85% for new equipment to approximately 50–65% after prolonged operation without major overhaul.

The shorter cold-start duration observed for the electric-heating system is also attributed to direct heat generation within the storage tank, eliminating the need to first heat and circulate thermal oil before transferring heat to the asphalt.

The engineering implications of this study extend beyond simple operating-cost reduction. For asphalt plants operating medium-capacity storage tanks, the adoption of electric-heating technology may reduce installation complexity, simplify preventive maintenance, improve temperature-control accuracy, and eliminate local combustion emissions. These advantages are particularly relevant for facilities located in industrial areas where stable electrical infrastructure is available.

Nevertheless, the selection of heating technology should remain site-specific. Facilities located in remote areas with unreliable electricity supply or limited electrical capacity may continue to require hot-oil systems despite their higher operating costs. Therefore, heating-system selection should consider not only thermal efficiency but also energy availability, operational continuity, maintenance capability, and long-term investment strategy.

Several limitations should be acknowledged. First, the engineering analysis is based on validated secondary engineering data and industrial operating assumptions rather than long-term field measurements. Second, equipment costs were estimated from industrial suppliers because detailed procurement prices are generally available only through official quotations. Third, the economic evaluation assumes constant electricity tariffs and diesel prices throughout the ten-year operating period and therefore does not incorporate future energy-price fluctuations. Finally, the present study evaluates only technical and economic performance and does not quantify indirect greenhouse-gas emissions associated with electricity generation. Future work should include experimental validation under industrial operating conditions, uncertainty and sensitivity analyses, and life-cycle environmental assessment to provide a more comprehensive evaluation of asphalt-heating technologies.

CONCLUSION

This study conducted a comparative engineering evaluation of hot-oil and electric heating systems for asphalt storage tanks with capacities ranging from 15 to 22 MT by considering technical design, thermal performance, and long-term economic performance under identical operating assumptions. The results demonstrate that the electric-heating system provides a simpler engineering configuration by eliminating the boiler, thermal-fluid circulation system, expansion tank, and associated auxiliary equipment required by the hot-oil system. This simplified configuration reduces installation complexity, installation time, maintenance requirements, and operator dependency while improving temperature-control accuracy. From an economic perspective, the electric-heating system requires a lower initial investment, significantly reduces annual operating expenditure, achieves a simple payback period of approximately 0.38 years (4.5 months), and decreases the ten-year life-cycle cost by approximately IDR 6.86 billion compared with the hot-oil alternative. Furthermore, the thermal-performance analysis indicates that direct electric heating maintains nearly 100% point-of-use thermal efficiency throughout its service life, whereas the thermal efficiency of the hot-oil system decreases over time because of combustion losses, equipment ageing, and thermal-fluid degradation. Nevertheless, the hot-oil system still offers better temperature uniformity, which may remain advantageous for larger storage capacities or applications requiring continuous large-scale heat distribution.

The principal scientific contribution of this study is the development of an integrated engineering comparison framework that combines technical design characteristics, thermal-performance indicators, and techno-economic evaluation for medium-capacity asphalt storage tanks. Unlike previous studies that primarily focus on either industrial electrification or individual economic indicators, this work integrates component-level engineering analysis with annual operating costs, payback period, life-cycle cost, and thermal-efficiency assessment under a consistent operating scenario. The results provide engineering evidence that can support the selection of heating technologies for asphalt storage facilities, particularly in regions with stable electrical infrastructure and increasing fossil-fuel prices. Consequently, the study contributes both to engineering decision-making and to the broader implementation of industrial process electrification in asphalt-storage applications.

Several limitations should be acknowledged. The analysis is based on validated secondary engineering data, manufacturer specifications, and engineering assumptions rather than long-term experimental measurements under industrial operating conditions. In addition, the economic evaluation assumes constant electricity tariffs and diesel prices throughout the service life and does not consider future energy-price fluctuations or inflation. The environmental assessment is also limited to direct operational performance and does not include a complete life-cycle environmental analysis of electricity generation or fuel production. Therefore, future research should include full-scale experimental validation, computational thermal modelling, uncertainty and sensitivity analyses, and comprehensive life-cycle assessment (LCA) to evaluate the environmental and economic performance of asphalt-heating systems under different operating capacities, climatic conditions, and energy-market scenarios.

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