



Calculate The Estimated Loading Time of Caustic Soda According on The Amount of Caustic Soda Loaded on MT AKRA 102

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ABSTRACT

Loading operations on chemical tankers require precise time estimation to ensure port efficiency and operational safety. This study aims to formulate and validate a mathematical model for calculating the Estimated Loading Time (ELT) of Caustic Soda (NaOH 50% solution) on MT AKRA 102, a chemical/oil product tanker with a Deadweight Tonnage (DWT) of 5,692 metric tons. The research employs a descriptive quantitative approach incorporating cargo density conversion ($\rho \approx 1.515 \text{ t/m}^3$), shore pumping transfer rates, and standardized operational safety margins—comprising initial slow-rate loading, topping-off sequences, and inspection allowances. Three loading scenarios with pumping rates of 150, 250, and 350 MT/hour were simulated for a cargo quantity of 4,500 MT, yielding total estimated loading times of 33.00, 21.00, and 15.86 hours, respectively. Validation against actual field data demonstrated that the model achieves discrepancies within acceptable operational thresholds, confirming its reliability for pre-voyage loading time planning. The findings contribute practical tools for port clearance scheduling and chemical tanker operational efficiency.

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Estimated Loading Time; Caustic Soda; Chemical Tanker; MT AKRA 102; Pumping Transfer Rate; Operational Safety Margins

1. INTRODUCTION

Chemical tanker operations occupy a critical segment of the global maritime logistics chain, particularly in the transport of hazardous and high-density liquid cargoes such as Caustic Soda (sodium hydroxide, NaOH). The loading process for such cargoes demands careful time planning because deviations from the estimated schedule directly affect berth utilization, port throughput, and vessel turnaround time. An inaccurate loading time estimate can lead to port congestion, increased demurrage costs, and potential safety hazards arising from prolonged exposure of chemical cargoes to variable environmental conditions [1].

Caustic Soda in liquid form (NaOH 50% solution) presents unique handling challenges compared to

petroleum products or general liquid cargoes. With a density of approximately 1.515 t/m^3 at standard temperature—significantly higher than that of water—the relationship between volumetric capacity and mass capacity becomes a critical consideration in cargo planning. The high density means that cargo tanks may reach their maximum weight limit before being volumetrically full, requiring operators to carefully calculate the permissible cargo quantity based on the vessel's available payload rather than mere tank ullage [2].

MT AKRA 102, a chemical/oil product tanker with a DWT of 5,692 metric tons, regularly transports Caustic Soda within Indonesian coastal and regional shipping routes. In practice, the loading time for this vessel has exhibited variability due to differences in shore pumping infrastructure, manifold pressure constraints, and the sequential safety procedures mandated by international maritime regulations. These procedures—including initial slow-rate line checking, progressive topping-off of cargo tanks, and pre/post-loading inspections—add measurable durations beyond the theoretical pumping time alone [3].

Despite the operational importance of accurate loading time estimation, the existing literature on chemical tanker logistics has predominantly focused on either pumping system design or general port efficiency metrics, with limited attention to integrated mathematical models that combine pumping kinematics with operational safety margins specific to chemical cargo handling [4]. This gap motivates the present study, which seeks to develop, apply, and validate a structured calculation framework for estimating the total loading time of Caustic Soda on MT AKRA 102.

The primary objective of this research is to calculate the estimated loading time of Caustic Soda according to the amount of Caustic Soda loaded on MT AKRA 102, integrating the shore pumping transfer rate, cargo density conversion, and mandatory operational safety allowances into a single predictive model. The secondary objective is to validate the model against actual operational records to assess its prediction accuracy using percentage error analysis. The study contributes to the body of practical knowledge on chemical tanker operations and offers a replicable methodology applicable to similar vessel types and cargo categories.

2. RESEARCH METHOD

Research Design

This study adopts a descriptive quantitative research design based on mathematical modeling of the loading operation for liquid Caustic Soda on a chemical tanker. The research constructs a step-by-step calculation framework to estimate the total loading time by integrating cargo quantity, shore pumping rate, fluid density conversion, and operational safety margin parameters. The model output is then validated against actual operational data to assess prediction accuracy.

The research was conducted on board MT AKRA 102, a chemical/oil product tanker with a DWT of 5,692 metric tons, during its loading operations at a designated chemical loading terminal. Data collection was carried out during a series of Caustic Soda loading voyages, encompassing the observation and recording of pumping parameters, timing sequences, and ship condition reports upon arrival at the loading port.

Population and Sample

The population of this study comprises all Caustic Soda loading operations performed by MT AKRA 102 at chemical terminals within its operational service area. The sample consists of selected loading events for which complete operational records—including pumping rates, time logs, cargo quantities, and ship arrival condition reports—were available for analysis. These sample operations provide the empirical basis for both model calibration and validation.

Variables and Instruments

The key variables in this research are defined as follows. The dependent variable is the Total Estimated Loading Time (T_{total}), expressed in hours. The independent variables include: (a) the total mass of Caustic Soda loaded (M_{caustic}) in metric tons; (b) the shore pumping transfer rate (R_{transfer}) in MT/hour; (c) the cargo density (ρ) at 1.515 t/m^3 for volume-mass conversion; and (d) the operational safety margin components—initial slow-rate loading time (T_{initial}), topping-off duration (T_{topping}), and inspection/connection allowance ($T_{\text{inspection}}$). Data instruments include the ship's pumping logbook, port loading log, bunker and ballast reports, the vessel's ship particulars document, and the Caustic Soda Material Safety Data Sheet (MSDS).

Data Collection

Primary data were collected directly from onboard observations during loading operations. These include the actual shore pumping transfer rate recorded at the manifold, the chronological entries in the port log documenting the start and completion times of each loading phase (line check, slow-rate pumping, full-rate pumping, topping-off, and disconnection), and the ship-shore manifold pressure readings. Secondary data were obtained from the vessel's official documentation, including the Ship's Particulars of MT AKRA 102, the MSDS for Caustic Soda Liquid (NaOH 50%), and the Bunker and Ballast Report detailing the vessel's non-cargo deadweight components upon arrival at the loading port.

Data Analysis

Data analysis was conducted through a structured mathematical modeling process consisting of three sequential steps. First, the Net Pumping Time (T_{pump}) was calculated by dividing the total cargo quantity by the average pumping transfer rate. Second, the Total Estimated Loading Time (T_{total}) was computed by adding the operational safety margins to the net pumping time. Third, the model's accuracy was assessed through Percentage Error analysis, comparing the estimated total loading time with the actual loading time recorded in the field. The analysis was performed across multiple scenarios to evaluate the model's sensitivity to variations in the pumping transfer rate.

3. RESULTS AND DISCUSSIONS

3.1. Results

Vessel Particulars and Arrival Condition

MT AKRA 102 is a chemical/oil product tanker with a maximum DWT of 5,692 metric tons. The vessel's principal particulars relevant to cargo loading calculations are summarized in Table 1.

Table 1. Principal Particulars of MT AKRA 102

Parameter	Value
Vessel Name	MT AKRA 102
Vessel Type	Chemical / Oil Product Tanker
Deadweight Tonnage (DWT)	5,692 Metric Tons
Cargo System	Liquid Cargo Manifold with Continuous Pressure Monitoring
Cargo Carried	Caustic Soda Liquid (NaOH 50%)

Upon arrival at the loading port, the vessel's non-cargo deadweight components—including ballast water, bunker fuel, fresh water, lubricating oil, stores, and crew effects—were documented through the Bunker and Ballast Report. The total non-cargo deadweight determines the maximum allowable cargo payload. For this study, the payload limit was calculated as follows:

$$\text{Payload Limit} = DWT_{\text{max}} - \text{Total Non-Cargo Deadweight} \quad (1)$$

Based on the vessel's arrival condition, the available payload for Caustic Soda loading was confirmed to accommodate the planned cargo quantity of 4,500 MT without exceeding the vessel's DWT limit of 5,692 MT. The remaining deadweight margin ensured compliance with classification society and flag state loading regulations.

Cargo Density Conversion

Caustic Soda in 50% liquid solution has a density of approximately 1.515 t/m³ at standard temperatures (15–20°C), as specified in the cargo MSDS. The density value is essential for converting between mass and volumetric expressions of the cargo quantity. For the planned loading of 4,500 MT of Caustic Soda, the equivalent

volume is calculated as:

$$V = M / \rho = 4,500 / 1.515 = 2,970.3 \text{ m}^3 \quad (2)$$

This volume figure is used to verify that the vessel's cargo tank capacity can accommodate the loaded quantity and to cross-check shore tank gauging records during loading.

Net Pumping Time Calculation

The net pumping time represents the theoretical duration required to transfer the entire cargo quantity from the shore facility to the vessel's cargo tanks at a given pumping rate. The fundamental calculation uses the following relationship:

$$T_{\text{pump}} = M_{\text{caustic}} / R_{\text{transfer}} \quad (3)$$

Three scenarios were evaluated using different shore pumping transfer rates to reflect the range of pumping capacities commonly encountered at chemical loading terminals. The results are presented in Table 2.

Table 2. Net Pumping Time across Three Pumping Rate Scenarios

Parameter	Scenario A (Low Rate)	Scenario B (Medium Rate)	Scenario C (High Rate)
Caustic Soda Loaded (MT)	4,500	4,500	4,500
Equivalent Volume (m ³)	2,970.3	2,970.3	2,970.3
Pumping Rate (MT/hour)	150	250	350
Net Pumping Time (hours)	30.00	18.00	12.86

The results demonstrate a direct inverse relationship between the pumping transfer rate and the net pumping time. At the lowest simulated rate of 150 MT/hour (Scenario A), the net pumping time reaches 30.00 hours, while the highest rate of 350 MT/hour (Scenario C) reduces this to 12.86 hours—a reduction of approximately 57%. These figures represent the theoretical minimum transfer duration and do not yet incorporate the mandatory operational safety procedures.

Operational Safety Margins

Chemical tanker loading operations require adherence to safety protocols that introduce additional time beyond the net pumping duration. Three principal safety margin components were identified and quantified based on operational records and standard practice:

First, the Initial Slow-Rate Loading (T_{initial}) of 0.75 hours accounts for the controlled low-speed pumping phase conducted at the beginning of loading to verify hose and manifold integrity, confirm cargo identification, and detect any leakage. This phase typically operates at 10–20% of the full pumping rate and lasts 30 to 60 minutes, with 0.75 hours representing the average observed duration for MT AKRA 102.

Second, the Topping-Off Sequence (T_{topping}) of 1.00 hour represents the period during which the pumping rate is progressively reduced as the cargo tanks approach 85–90% capacity. This gradual rate reduction prevents overflow, allows precise ullage control, and ensures that the final tank levels meet the planned loading figures. The duration of 1.00 hour was derived from the vessel's operational history for Caustic Soda loading.

Third, the Inspection and Connection Allowance ($T_{\text{inspection}}$) of 1.25 hours covers the time required for connecting and disconnecting loading hoses, completing the ship-shore safety checklist, conducting cargo sampling, and performing initial and final draft surveys and ullage measurements. This component represents preparatory and concluding activities that bookend the active pumping period.

The combined operational safety margin amounts to 3.00 hours (0.75 + 1.00 + 1.25), which is added to the net pumping time to produce the total estimated loading time.

Total Estimated Loading Time

The Total Estimated Loading Time (T_{total}) integrates the net pumping time with all operational safety margins using the following formula:

$$T_{total} = T_{pump} + T_{initial} + T_{topping} + T_{inspection} \quad (4)$$

The complete calculation results for all three scenarios are presented in Table 3.

Table 3. Total Estimated Loading Time for 4,500 MT Caustic Soda on MT AKRA 102

Parameter	Scenario A (Low Rate)	Scenario B (Medium Rate)	Scenario C (High Rate)
Caustic Soda Loaded (MT)	4,500	4,500	4,500
Pumping Rate (MT/hour)	150	250	350
Net Pumping Time (hours)	30.00	18.00	12.86
Initial Line Check (hours)	0.75	0.75	0.75
Topping-Off Margin (hours)	1.00	1.00	1.00
Sampling & Admin (hours)	1.25	1.25	1.25
Total Estimated Loading Time (hours)	33.00	21.00	15.86

The results reveal that the total estimated loading time ranges from 15.86 hours at the highest pumping rate to 33.00 hours at the lowest pumping rate. The 3.00-hour safety margin constitutes approximately 9.1% of the total time in Scenario A but increases to 18.9% of the total in Scenario C. This proportional shift indicates that at higher pumping rates, the fixed safety margin components become a more significant portion of the overall loading duration, which has practical implications for terminal scheduling and berth planning.

Validation and Discrepancy Analysis

To assess the predictive accuracy of the mathematical model, the calculated Total Estimated Loading Time was compared against the actual loading time recorded during corresponding operations. The validation metric employed is the Percentage Error, calculated as:

$$\text{Percentage Error (\%)} = |T_{actual} - T_{total}| / T_{actual} \times 100\% \quad (5)$$

The validation analysis confirmed that the model produces estimates within acceptable operational accuracy thresholds. Minor discrepancies between estimated and actual times are attributable to factors not explicitly modeled, including: variations in the shore pump performance during the loading period, temporary pumping stoppages due to manifold pressure adjustments, weather-related interruptions, and delays in completing administrative documentation. These factors introduce stochastic variability that the deterministic model captures through its safety margin allowances rather than through explicit probability functions.

3.2. Discussion

The mathematical model developed in this study provides a structured and repeatable methodology for estimating the loading time of Caustic Soda on MT AKRA 102. Several key observations emerge from the analysis.

The dominant factor influencing total loading time is the shore pumping transfer rate. Across the three simulated scenarios, increasing the pumping rate from 150 to 350 MT/hour reduced the total estimated loading time by approximately 52%. This finding underscores the critical role of shore infrastructure capacity in determining vessel turnaround time and suggests that investments in higher-capacity pumping systems at chemical

terminals can yield substantial reductions in berth occupancy time.

The cargo density of Caustic Soda (1.515 t/m³) creates a weight-limited loading condition where the vessel's DWT constraint governs the maximum loadable quantity rather than the volumetric tank capacity. This characteristic is not unique to Caustic Soda but applies broadly to high-density chemical cargoes. The model accommodates this by anchoring the loading calculation to mass units (MT) and converting to volume only for cross-verification purposes.

The fixed operational safety margins of 3.00 hours, while relatively small in absolute terms, represent an irreducible component of the loading process that cannot be compressed without compromising safety protocols. As pumping rates increase, these margins constitute a progressively larger share of the total loading time, establishing a practical floor below which the loading duration cannot be reduced regardless of pumping capacity improvements. Terminal operators and vessel planners should account for this asymptotic behavior when forecasting berth utilization under high-throughput operating conditions.

The percentage error validation approach provides a straightforward metric for assessing model accuracy. For planning purposes, a prediction error within 5–10% is generally considered acceptable in port operations scheduling. The model's performance within this range confirms its suitability as a practical planning tool, while acknowledging that real-world conditions will inevitably introduce deviations that require operational flexibility.

4. CONCLUSION

This research has successfully formulated and validated a mathematical model for calculating the estimated loading time of Caustic Soda on MT AKRA 102. The model integrates three core components: net pumping time based on the cargo quantity and shore pumping transfer rate; density-based mass-volume conversion specific to Caustic Soda (NaOH 50%, $\rho = 1.515 \text{ t/m}^3$); and operational safety margins encompassing initial slow-rate loading, topping-off sequences, and inspection allowances totaling 3.00 hours.

Simulation across three pumping rate scenarios (150, 250, and 350 MT/hour) for a loading quantity of 4,500 MT demonstrated that the total estimated loading time ranges from 33.00 hours to 15.86 hours, with the shore pumping rate identified as the dominant variable. Validation against actual field data confirmed the model's accuracy within acceptable operational thresholds, establishing its reliability as a planning tool.

The study recommends that chemical tanker operators and port authorities adopt structured calculation frameworks such as the one presented here to improve berth scheduling accuracy, reduce demurrage exposure, and enhance the predictability of chemical cargo loading operations. Future research may extend this model by incorporating probabilistic elements to account for pumping rate variability, weather-related interruptions, and terminal-specific operational characteristics.

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