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Simulation of Performance of Heater Treater Using MATLAB

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ABSTRACT

This study presents a comprehensive performance evaluation of Heater Treater operating at oil and gas Field, The unit's performance was assessed through analytical modeling and MATLAB simulation using field operating data to determine three key parameters: effective length, retention time, and heat duty. The analysis employed established correlations for gravitational settling, residence time, and thermal requirements to compare actual operating conditions with design specifications. The results show that the unit currently operates beyond its design capacity at a throughput of 5600 bbl/day, leading to excessive heat duty (3.9 MMBtu/h > 2.2 MMBtu/h design), insufficient retention time (~20 min), and inadequate effective length for complete oil–water separation. Optimal performance was achieved only within the flowrate range of 1100–2900 bbl/day, where all parameters remain within safe and efficient limits. The findings indicate that reactivating the preheater and maintaining the optimal operating window would significantly improve dehydration efficiency, reduce thermal load, and extend equipment life.

Keywords: Heater Treater, Performance Evaluation, Retention Time, Heat Duty, Crude Oil Emulsion

1. INTRODUCTION

Crude oil extracted from production wells is rarely a single-phase fluid; it is typically a complex mixture that includes formation water, dissolved salts, and fine solids [1]. The intense shear and pressure drops experienced during production, such as flow through chokes and valves, provide sufficient mixing energy to disperse the water phase as fine droplets within the continuous oil phase, forming stable water-in-oil (W/O) emulsions [2]. These emulsions are stabilized by a variety of naturally occurring surface-active components indigenous to heavy crude oil, such as asphaltenes and resins, which accumulate at the oil-water interface to form a rigid, viscoelastic film that hinders droplet coalescence [3][4]. The formation of such stable emulsions presents significant operational challenges, including increased fluid viscosity that elevates pumping costs, higher risks of pipeline corrosion from saline water, and potential catalyst poisoning in downstream refining processes [5]. Consequently, to meet sales specifications—which typically mandate a Basic Sediment and Water (BS&W) content of less than 1.0%—effective demulsification is a critical step in crude oil processing [6].

Various demulsification techniques are employed in the industry, including chemical, electrical, and physical methods [7]. Among these, thermal treatment is one of the most widely applied strategies for breaking stable W/O emulsions. The heater treater is a specialized vessel that integrates multiple separation principles, primarily combining thermal energy input with gravitational settling to facilitate demulsification [8]. The fundamental purpose of a heater treater is to apply heat to the emulsion, which reduces the viscosity of the continuous oil phase and weakens the stabilizing interfacial films [9]. This reduced viscosity enhances droplet mobility, while the weakened film promotes the coalescence of smaller water droplets into larger ones. Given sufficient retention time within the vessel's settling section, these larger, denser water droplets then separate from the oil phase under gravity [10].

The operational effectiveness of a heater treater is governed by a set of interconnected design parameters that must be carefully balanced to achieve optimal performance [11]. Key among these are the heat duty required to reach the target operating temperature, the retention time necessary for adequate phase separation, and the effective settling length of the vessel [12]. While these parameters are established during the initial design phase, their relevance can change significantly over the equipment's operational life. Field operations often deviate from original design premises due to factors such as variations in crude oil throughput, changes in emulsion characteristics, and the progressive accumulation of scale deposits on heat transfer surfaces [13].

Failure analyses of in-service heater treaters have consistently shown that prolonged operation, especially beyond design capacity, can lead to significant material degradation and performance decline [8]. The formation of scale on the fire tube's exterior, for instance, can act as an insulating layer, impeding heat transfer to the emulsion and causing localized overheating of the tube metal [9]. This condition leads to severe thermal stress concentration, which may ultimately result in mechanical failure such as cracking and rupture, leading to production downtime and safety hazards [8][9]. Such operational challenges underscore the critical need for systematic performance evaluations of existing heater treater units to validate their efficiency under actual field conditions, rather than relying solely on theoretical design calculations. It is also essential to ensure that all safety systems and protective devices are appropriately designed and maintained according to industry standards, such as API 14C, to mitigate these risks [14].

Therefore, the present study aims to conduct a comprehensive performance evaluation of Heater Treater equipment operated by oil and gas company. This work seeks to bridge the gap between established design theory and actual field operational data to assess the unit's efficiency under its current throughput. The primary objectives of this research are: (1) to calculate the required effective length, retention time, and actual heat duty of the heater treater based on field operational data using established empirical models; (2) to compare these calculated performance metrics with the equipment's design specifications to identify and quantify any operational performance gaps; and (3) to determine an optimal operating flowrate range that ensures the crude oil consistently meets the BS&W specification of $\leq$ 0.05% while maintaining safe and efficient operation.

2. MATERIALS AND METHODS

2.1 Materials

The evaluation was conducted as a case study at the oil processing facility. The primary unit of analysis was the Heater Treater. The data required for this performance analysis were obtained through a combination of field studies and a review of plant documentation. The design specifications of Heater Treater were sourced from the plant's Piping and Instrumentation Diagram (P&ID) and equipment datasheets, as summarized in Table 1.

Table 1. Design Specifications of Heater Treater

Parameter	Value	Unit
Item Number	SB-XYZ	-
Type	Chem/Electric Heater Treater	-
Orientation	Horizontal	-
Vessel Size (Diameter x Lenght)	96 in x 25 ft	-
Design Pressure	50	Psig
Design Temperature	200	°F
Designt Heat Duty	2.2	MMBtu/h

Operational data were collected from field records and control systems during the study period. The key parameters used for the analysis are presented in Table 2. Where direct measurements were unavailable, established assumptions based on literature and fluid properties were applied

Table 2. Operational Data and Assumed Parameters for Analysis

Parameter	Value	Unit	Source/note
Oil flowrate (Q)	5600	bbl/day	Field Data
Oil Inlet Temperature	~75	°F	Field Data
Operating Temperature	160	°F	Field Data
Oil API Gravity	40	°API	Laboratory Analysis
BS&W Target	0.05	%	Company Specification
Water Specific Gravity (SGw)	1.04	-	Assumed
Oil Viscosity (μ) at 160°F	1,2	cP	Assumed
Effective Length (L_{eff})	12.5	ft	Assumed as 50% of total length

2.2 Experimental procedure

The performance evaluation of Heater Treater equipment was conducted through a systematic procedure that integrated literature study, field data collection, computational analysis, and result validation. The methodology began with a comprehensive literature review to identify appropriate mathematical models and equations from established references, followed by field data collection at oil and gas company to gather design specifications and operational parameters. The core analysis phase utilized MATLAB programming to simulate performance across various operating conditions, implementing algorithms for the settling equation, retention time calculation, and heat duty analysis. The simulation results were then validated against field observations and design specifications before finalizing recommendations for operational optimization. This systematic approach, illustrated in Figure 1, ensured a comprehensive evaluation of the heater treater's performance under actual operating conditions.

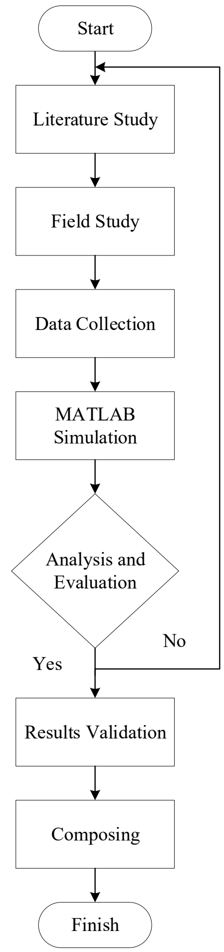

Figure 1. Flow chart research

2.3 Methods of analysis

The performance evaluation of Heater Treater was based on three fundamental criteria: separation efficiency governed by settling theory, sufficient retention time for phase separation, and adequate heat transfer capacity. The mathematical models used for these analyses are derived from established literature in petroleum engineering and heater treater design [13]. The key equations were implemented in MATLAB for computational simulation and analysis across a range of flow rates.

2.3.1 Analysis of Separation Efficiency (Settling Equation)

The ability of the heater treater to separate water droplets from oil depends on the gravitational settling velocity. The required vessel dimensions for effective separation were determined using the settling equation [13] :

$$d \cdot L_{eff} = 438 \frac{Q\,\mu}{\Delta SG\, d_m^2} \qquad (1)$$

Where :

d = vessel diameter (in)

L_{eff} = effective length of the coalescing section (ft)

Q = oil flow rate (bbl/day)

μ = oil viscosity (cP)

ΔSG = difference in specific gravity between water and oil ($SG_w - SG_0$)

d_m = diameter of the water droplet to be removed (µm)

The specific gravity of oil (SG_0) was calculated from the API gravity using the standard conversion :

$$SG_O = \frac{141{,}5}{API + 131{,}5} \qquad (2)$$

The target water droplet size (d_m) for a given BS&W was estimated using empirical correlations. First, the baseline droplet size at 1% water cut was calculated as [13] :

$$d_{m(1\%)} = 200\mu^{0,25} \quad (3)$$

Then, for the target BS&W of 0.05%, the droplet size was adjusted using an empirical power law correlation commonly applied in heater treater design :

$$d_{m(wc)} = d_{m(wc)} \times W_c^{0,33} \quad (4)$$

where W_c is the water cut in decimal form (0.0005 for 0.05% BS&W).

2.3.2 Analysis of Retention Time

Adequate retention time is essential for water droplets to coalesce and settle. The available retention time (τ) in the coalescing section was calculated using[13] :

$$d^2 \cdot L_{eff} = \frac{Q\,t_r}{1,05} \quad (5)$$

A minimum retention time of 20 minutes is recommended for effective separation in heater treaters

2.3.3 Analysis of Heat Duty

The heat required to raise the temperature of the oil-water mixture to the operating temperature was calculated using [13] :

$$q = 16Q\Delta T[0,5\,SG_o + 0,1] \quad (6)$$

Where :

q = heat duty (MMBtu/h)
ΔT = temperature increase ($T_{\text{operating}} - T_{\text{inlet}}$) (°F)

The calculated heat duty was compared to the design capacity of the heater treater's fire tube (2.2 MMBtu/h) to assess thermal performance. These equations were programmed into MATLAB to simulate performance across flow rates from 1000 to 8000 bpd, enabling the identification of the optimal operating range where all criteria (settling, retention time, and heat duty) are satisfied simultaneously.

3. RESULTS AND DISCUSSION

3.1 Overview of Heater Treater Operation

The heater treater is a vital separation unit in crude oil production facilities, serving separate oil, water, and gas phases through controlled heating. The heat supplied reduces crude oil viscosity and facilitates the coalescence of dispersed water droplets, improving phase separation efficiency.

Heater Treater equipment, operated in Oil and gas plant, is a horizontal chcem/electrical type vessel with a diameter of 96 inches and a length of 25 ft. The equipment is designed to operate at a pressure of 20–40 psig and a temperature of 160 °F, with a maximum heat duty of 2.2 MMBtu/h. The feed crude oil has an API gravity of 40 and an inlet temperature of approximately 75 °F.

This study evaluates the unit's performance by comparing the effective length (Leff), retention time, and heat duty values obtained from calculations with the actual design parameters, to determine the operational limits and efficiency of the heater treater.

3.2 Calculation Overview

The performance evaluation of Heater Treater was conducted based on three main parameters: effective length (Leff), retention time, and heat duty. These parameters were calculated using standard correlations described in Section 2, considering crude oil properties (API 40), operating pressure (30 psig), and temperature (160 °F).

The effective length (Leff) determines the adequacy of the separation zone for gravitational settling of water droplets, while the retention time indicates how long the emulsion mixture remains inside the vessel. The heat duty reflects the energy required to achieve the desired outlet temperature and ensure proper viscosity reduction. All calculation results are summarized in Table 3, which provides the basis for graphical analysis in Figures 3–5.

Table 3 serves as the numerical basis for analyzing the effects of flowrate on each performance parameter, as discussed in the following subsections.

3.3 Effective Length (L_{eff}) Analysis

The effective length (L_{eff}) represents the required separation zone length for water droplets to settle completely before the crude oil leaves the heater treater. The relationship between flowrate and effective length is presented in Figure 2.

As shown in the figure, the $L_{eff\_required}$ value increases sharply with higher flowrates, while L_{eff_actual} remains constant at 1200 in.ft, corresponding to the physical design limit of the vessel. At lower flowrates (1000–2900 bbl/day), the $L_{eff\_required}$ curve remains below L_{eff_actual}, indicating sufficient separation space for efficient three-phase separation (oil–water–gas).

However, when the flowrate exceeds 3000 bbl/day, the $L_{eff\_required}$ line surpasses the L_{eff_actual} limit, implying that the available separation zone becomes inadequate. Under the current operating condition of 5600 bbl/day, the $L_{eff\_required}$ value is nearly twice the actual effective length, meaning that many water droplets cannot settle before exiting the vessel. This condition results in increased water carryover and reduced dehydration efficiency. Furthermore, rapid compression in pressurized systems is known to produce significant temperature rises within seconds, which can influence fluid behavior and exacerbate separation limitations [15]

Table 3. Calculation results of Heater Treater

Flowrate (bbl/d)	L_{eff_req} (in.ft)	L_{eff_act} (in.ft)	Retention TIme (min)	Duty (MMBtu/h)
1000	403,08	1200	120,96	0,6971
2000	806,16	1200	60,48	1,3941
3000	1209,20	1200	40,32	2,0911
4000	1612,30	1200	30,24	2,7882
5000	2015,40	1200	24,19	3,4852
6000	2418,50	1200	20,16	4,1823
7000	2821,60	1200	17,28	4,8793
8000	3224,70	1200	15,12	5,5764

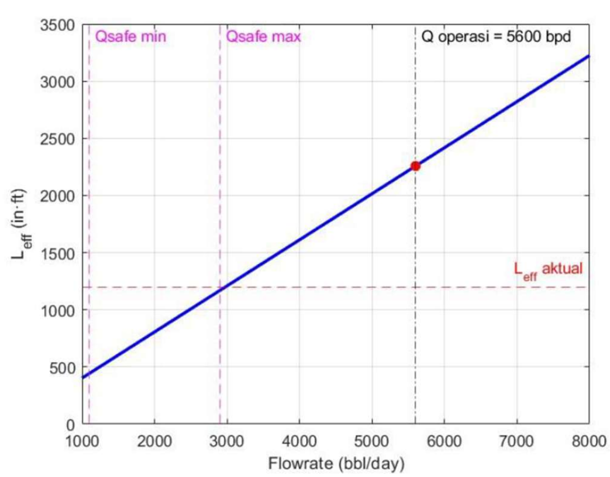

Figure 2. Relationship between flowrate and effective length (Leff) of Heater Treater.

Consequently, a thicker emulsion band forms inside the heater treater, which hampers the separation process. Based on the analysis, the optimal operating range for Heater Treater is 1100–2900 bbl/day, while the current rate of 5600 bbl/day exceeds the design limit, resulting in suboptimal performance.

3.4 Retention Time Analysis

Retention time is one of the most critical parameters for determining separation performance, as it represents how long the fluid mixture remains inside the vessel to allow gravity-based settling. The correlation between flowrate and retention time is presented in Figure 3.

Figure 3 shows that the retention time decreases exponentially with increasing flowrate. At low flowrates, the fluid remains inside the vessel long enough to allow efficient water droplet coalescence and settling. However, when the flowrate surpasses approximately 3000 bbl/day, the retention time drops below the minimum design criterion of 30–40 minutes required for crude oil with API 40.

At the current operating flowrate of 5600 bbl/day, the retention time falls to around 20 minutes, which is insufficient for complete separation. This short residence period leads to partial dehydration and increased BS&W (Basic Sediment and Water) content in the outlet stream.

This behavior aligns with theoretical predictions: as flowrate rises, fluid velocity increases and residence time decreases, leading to incomplete gravitational settling. Maintaining the flowrate within 1100–2900 bbl/day ensures sufficient retention for effective oil–water separation and stable product quality.

3.5 Heat Duty Analysis

The heat duty represents the total energy required to raise the crude oil temperature from inlet to outlet conditions. The relationship between flowrate and heat duty is illustrated in Figure 4.

As observed, heat duty increases almost linearly with flowrate. Within the range of 1000–2900 bbl/day, the required heat duty stays below the design capacity of 2.2 MMBtu/h, allowing stable operation and efficient heating. Beyond this range, the duty rises sharply, exceeding the design limit.

At the current field condition (5600 bbl/day), the heat duty reaches approximately 3.9 MMBtu/h, which is around 75% higher than the design capacity. Such a high thermal load may cause excessive energy consumption, overheating, and accelerated fouling of the heating elements. This not only reduces heat transfer efficiency but can also impact the dehydration process by disrupting the temperature control of the oil–water mixture.

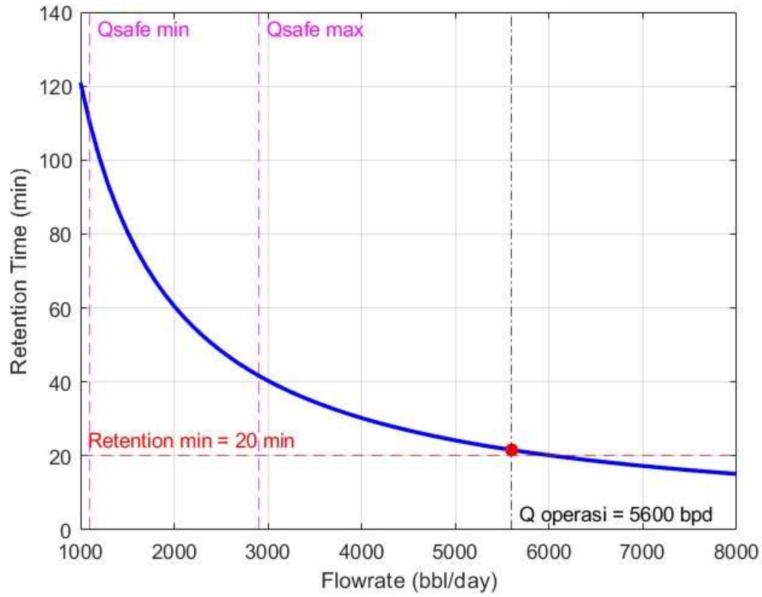

Figure 3. Relationship between flowrate and retention time in Heater Treater

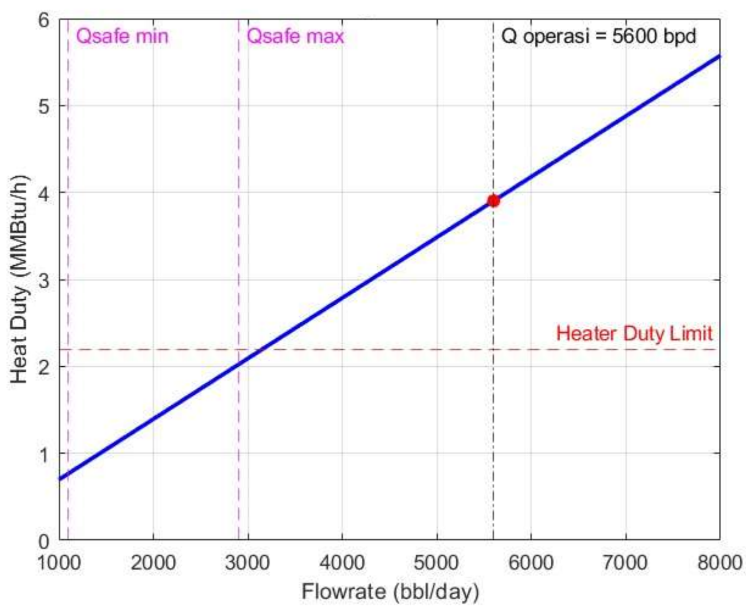

Figure 4. Correlation between flowrate and heat duty requirement of Heater Treater

These results show that the existing heater configuration is no longer adequate for the current production rate. Therefore, the installation of a preheater to pre-warm the crude oil before entering the heater treater is recommended to reduce the main heater load. Additionally, periodic monitoring of temperature, viscosity, and BS&W content is necessary to maintain optimal separation and thermal performance.

Based on the three analyzed parameters—effective length, retention time, and heat duty—the overall evaluation indicates that Heater Treater is currently operating beyond its design capacity at a throughput of 5600 bbl/day. The required effective length and heat duty substantially exceed the design specifications, while the retention time falls below the minimum value necessary for stable phase separation. The combined effects of high flowrate and limited vessel dimensions result in incomplete oil–water separation, elevated BS&W (Basic Sediment and Water) content, and increased energy consumption. To sustain operational reliability and separation efficiency, it is recommended that the existing preheater, which is currently bypassed, be reutilized in operation to reduce the thermal load on the main heater treater. Maintaining the unit within the optimal flowrate range of 1100–2900 bbl/day and conducting routine monitoring of viscosity, BS&W, and temperature profiles are also essential to ensure stable operation and extend equipment lifespan. Overall, these findings confirm that the heater treater performs effectively under moderate flowrates but requires operational optimization through the reactivation of the preheater to handle the current production demand efficiently.

4. CONCLUTION

The performance evaluation of Heater Treater at oil and gas Field reveals that the unit is operating beyond its design capacity under the current throughput of 5600 bbl/day. The effective length requirement and heat duty both exceed design specifications, while the retention time is insufficient for complete oil–water separation. Optimal performance is achieved within a flowrate range of 1100–2900 bbl/day, where all parameters remain within safe operational limits.

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CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Mirza Aqeel Fernanda: Formal Analysis, MATLAB Simulation, Validation, Writing – Review & Editing.
Muhammad Revansyah Ramadhani W.: Conceptualization, Methodology, Data Curation, Writing – Original Draft.
Erwan Adi Saputro: Supervision, Resources, Project Administration, Writing – Final Revision.

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