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Performance Analysis of a 250 m³ SS316L Tank Hydrotest System Using the Water Filling Method with a Centrifugal Pump

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***Abstract*—*Hydrostatic testing (hydrotest) is a method used to verify the structural strength, integrity, and leak tightness of storage tanks before commissioning. The performance of the hydrotest process is influenced by the pumping system, piping configuration, and the increase in hydrostatic pressure during the filling process. This study aims to analyze the actual operating condition of a 250 m³ SS316L storage tank hydrotest system using a centrifugal pump, determine the actual flow rate, evaluate the effect of hydrostatic head on filling time, and identify the causes of hydrotest delays under actual operating conditions. A quantitative approach was employed using the Continuity Equation, Bernoulli Equation, and Darcy–Weisbach Equation to analyze the actual flow rate, head loss, hydrostatic head, hydrostatic pressure, suction and discharge pressure, Total Dynamic Head (TDH), pump power, and filling time. The results indicate that the actual flow rate decreased from 2.67 m³/h to 0.512 m³/h as the hydrostatic head increased from 2.61 m to 10.45 m. Total head loss remained relatively low, ranging from 0.281 m to 0.016 m, while the TDH ranged from 13.203 m to 13.096 m. Hydraulic power decreased from 96.105 W to 18.243 W, and pump power decreased from 216.94 W to 41.18 W. The total actual filling time reached 264.47 hours and increased to 318.47 hours after including the holding time. The study concludes that the increase in hydrostatic head is the primary factor responsible for the reduction in actual flow rate and the extension of hydrotest duration, whereas piping head loss has only a minor effect on overall system performance.*

Keywords*— *Hydrotest, Centrifugal Pump, Hydrostatic Head, Total Dynamic Head, Filling Time.

I. Introduction

Hydrostatic testing (hydrotest) is a mandatory procedure performed before a storage tank is commissioned to verify its structural integrity, material strength, and weld quality in accordance with the American Petroleum Institute (API) 650 standard. In atmospheric storage tanks, the testing pressure is generated by the increasing hydrostatic head during the water filling process. Therefore, the performance of the pumping system plays an important role in determining the efficiency and duration of hydrotest operations. Prayoga and Kasturi (2025) reported that the actual performance of centrifugal pumps in industrial applications often decreases due to increasing system head and energy losses (head loss) within the piping system. Similarly, Kasturi and Meilani (2025) stated that an increase in system head may reduce the actual flow rate compared with the pump manufacturer's rated capacity.

Previous studies have mainly focused on centrifugal pump performance under laboratory conditions or operating conditions close to the manufacturer's specifications. However, studies evaluating hydrotest system performance under actual field operating conditions remain limited, particularly those investigating the relationship between increasing hydrostatic head, changes in actual flow rate, and their influence on filling time during storage tank hydrotesting. This research gap indicates the need for an evaluation based on actual operational data to better represent field conditions.

In this study, the hydrotest process was carried out using a centrifugal pump with a top-filling method through an open manhole (free discharge). The suction line employed PVC piping supplied by raw water, while the discharge line used a nylon braided hose to deliver water to the top of a 250 m³ SS316L storage tank. During operation, the hydrostatic head continuously increased as the water level rose, resulting in higher system resistance and changes in pump operating conditions. These conditions were expected to affect the actual flow rate, filling time, and overall hydrotest performance.

Therefore, this study aims to analyze the actual performance of the hydrotest system by evaluating the actual flow rate, head loss, hydrostatic head, Total Dynamic Head (TDH), pump power, and filling time. Furthermore, the study investigates the influence of increasing hydrostatic head and actual operating conditions on hydrotest performance and evaluates the factors contributing to the delay between the planned and actual hydrotest duration. The results are expected to provide technical references for improving hydrotest system performance and optimizing pumping system operation in industrial storage tank applications.

II. Materials and Methods

A. Design of Hydrotest System

This study employed a quantitative research method using a case study approach to investigate the hydrotest process of a 250 m³ SS316L storage tank using a centrifugal pump with the water filling method. The quantitative approach was selected because the study was based on the measurement and analysis of numerical data, including the actual flow rate, filling time, pressure, head loss, hydrostatic head, hydrostatic pressure, Total Dynamic Head (TDH), and pump power obtained during the hydrotest process. These data were subsequently analyzed using fundamental fluid mechanics equations to quantitatively describe the relationships among the investigated variables.

The study was conducted during the hydrotest of a 250 m³ SS316L storage tank at a tank construction project site. The hydrotest system consisted of a centrifugal pump, PVC piping on the suction side, a PVC spiral hose, and a nylon braided hose on the discharge side. During the filling process, water was pumped to the top of the tank through an open manhole (top filling) so that the water level gradually increased from 25%, 50%, and 75% to 100% of the tank capacity. The increase in water level continuously raised the hydrostatic head, thereby affecting the hydraulic characteristics of the system and the pump operating point.

The objective of this study was to analyze the actual performance of the hydrotest system under different water levels during the tank filling process. The analysis included the determination of the actual flow rate, flow velocity, Reynolds number, Darcy friction factor, major loss, minor loss, total head loss, hydrostatic head, hydrostatic pressure, suction and discharge pressures, Total Dynamic Head (TDH), hydraulic power, pump power, and the effect of increasing hydrostatic head on the filling time. The findings are expected to identify the dominant factors responsible for the prolonged hydrotest duration and to provide a technical basis for improving the efficiency of hydrotest systems used in storage tank applications.

B. *Experimental Setup*

The hydrotest system was assembled and installed at the project site to evaluate the actual performance of a 250 m³ SS316L storage tank during the water filling process. The system consisted of a centrifugal pump, a PVC suction pipeline, a PVC spiral hose, a nylon braided hose on the discharge side, manual valves, unions, and other supporting piping components. The pump suction was fed raw water at about 2 bar(g), and the discharge flow was sent through an open manhole at the top of the storage tank (top filling).

During the hydrotest process, the water level inside the tank increased gradually from 25%, 50%, 75%, to 100% of the tank capacity. The increase in water level resulted in a corresponding increase in hydrostatic head, which affected the pump operating conditions and the actual system performance. The actual flow rate, filling time, hydrostatic head, hydrostatic pressure, head loss, suction pressure, discharge pressure, Total Dynamic Head (TDH), hydraulic power, and pump power were determined based on field measurements and analytical calculations using fluid mechanics equations.

The actual hydrotest system configuration used in this study is illustrated in Fig. 2.

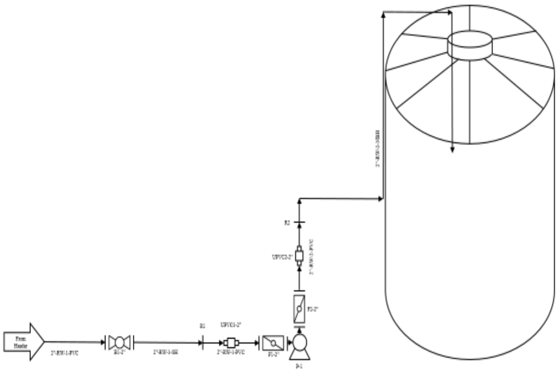

Fig. 1. Piping Diagram of Hydrotest System.

Fig. 2. Actual piping installation in hydrotest system

C. *Research Procedure*

The research procedure adopted in this study is illustrated in the flowchart shown in Fig. 3. The procedure began with problem identification, literature review, and field observation to understand the actual hydrotest system configuration. Subsequently, the specifications of the centrifugal pump, storage tank, piping system, and hydrotest operating conditions were collected as the basis for the analysis.

The hydrotest was then carried out using the water filling method by pumping raw water into a 250 m³ SS316L storage tank through an open manhole (top filling). During the filling process, operational data, including filling time, water level, and actual flow rate, were recorded at four filling stages (25%, 50%, 75%, and 100% tank capacity).

The collected data were subsequently processed using the Continuity Equation, Bernoulli Equation, and Darcy–Weisbach Equation to determine the actual flow rate, flow velocity, Reynolds number, friction factor, major loss, minor loss, hydrostatic head, hydrostatic pressure, suction and discharge pressures, Total Dynamic Head (TDH), hydraulic power, pump power, and filling time. Finally, the calculated results were analyzed and discussed to evaluate the effect of increasing hydrostatic head on the hydrotest system performance and to identify the factors contributing to the delay in the actual hydrotest process compared with the planned schedule.

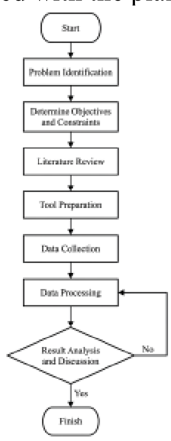

Fig. 3. Research flowchart for Performance Analysis of Hydrotest System.

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D. Flow Rate Measurement

The actual flow rate during the hydrotest process was determined using the volumetric method. The flow rate was calculated based on the volume of water filled into the storage tank and the corresponding filling time recorded at each filling stage (25%, 50%, 75%, and 100% of the tank capacity). The measured flow rate was used as the primary parameter for evaluating the hydrotest system performance and for calculating the hydraulic characteristics of the piping system.

E. Hydraulic Parameters Calculation

The hydraulic parameters analyzed in this study include the actual flow rate, flow velocity, Reynolds number, friction factor, hydrostatic head, hydrostatic pressure, suction head, discharge head, and Total Dynamic Head (TDH). These parameters were calculated using fundamental fluid mechanics equations.

The actual flow rate is determined by :

$$Q = \frac{V}{t} \quad (1)$$

where Q is the flow rate (m^3/s), V is the water volume (m^3), and t is the filling time (s).

The flow velocity is calculated using the continuity equation

$$V = \frac{Q}{A} \quad (2)$$

where V is the flow velocity (m/s) and A is the pipe cross-sectional area (m^2).

The Reynolds number is calculated as :

$$Re = \frac{VD}{v} \quad (3)$$

where Re is the Reynolds number, ρ is the fluid density (kg/m^3), V is the flow velocity (m/s), D is the pipe diameter (m), and μ is the dynamic viscosity (Pa·s).

F. Head Loss and Total Dynamic Head Calculation

The energy balance of the hydrotest piping system was analyzed using Bernoulli's equation, which considers pressure head, velocity head, elevation head, and total head loss.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 + h_p = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + h_L \quad (4)$$

where P is the pressure (Pa), ρ is the fluid density (kg/m³), V is the flow velocity (m/s), g is gravitational acceleration (9.81 m/s²), Z is the elevation head (m), h_p is the pump head (m), and h_L is the total head loss (m).

The major head loss due to pipe friction is determined using the Darcy–Weisbach equation :

$$hf = f\frac{L}{D}\frac{V^2}{2g} \quad (5)$$

where hf is the major head loss (m), f is the Darcy friction factor, L is the pipe length (m), and D is the pipe diameter (m).

The Darcy friction factor was determined from the Moody diagram using the calculated Reynolds number and the relative roughness of the pipe material. The Moody diagram used in this study is presented in Fig. 4.

The minor head loss caused by valves, unions, and free discharge is calculated as :

$$h_m = K\frac{V^2}{2g} \quad (6)$$

where h_m is the minor head loss (m) and K is the loss coefficient of each piping component.

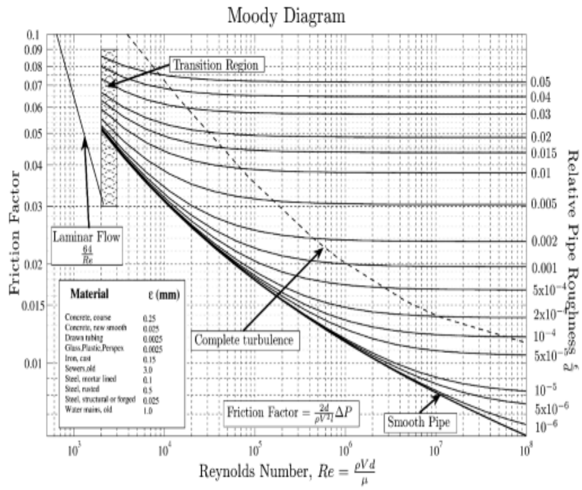

Fig. 4. Moody diagram used to determine the Darcy friction factor based on Reynolds number and relative roughness

The total head loss is calculated by :

$$hL = hf + hm \quad (7)$$

The Total Dynamic Head (TDH) of the hydrotest system is then obtained by combining the suction head and discharge head :

$$TDH = Hd + Hs \quad (8)$$

where Hd is the discharge head (m) and Hs is the suction head (m).

G. Pump Power Calculation

The hydraulic power transferred by the pump to the fluid is calculated using :

$$Ph = \rho gQH \quad (9)$$

where Ph is the hydraulic power (W), Q is the flow rate (m³/s), and H is the Total Dynamic Head (m).

The pump input power is determined by considering the pump efficiency :

$$P_p = \frac{P_h}{\eta} \quad (10)$$

where P_p is the pump power (W) and η is the pump efficiency.

H. Filling Time Analysis

The filling time required for each stage of the hydrotest process was calculated using :

$$t = \frac{V}{Q} \quad (11)$$

where t is the filling time (h), V is the water volume (m³), and Q is the actual flow rate (m³/h).

The total hydrotest duration was obtained by adding the total filling time and the holding time specified in the hydrotest procedure. The calculated results were then compared with the theoretical hydrotest duration based on the pump catalog and the actual hydrotest duration observed in the field to evaluate the causes of hydrotest delay.

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III. Results and Discussion

A. Actual Flow Rate

The actual flow rate was determined from the measured filling time at each water level during the hydrotest process. The results indicate that the flow rate continuously decreased as the water level inside the storage tank increased. The relationship between tank level and actual flow rate is presented in Fig. 4.

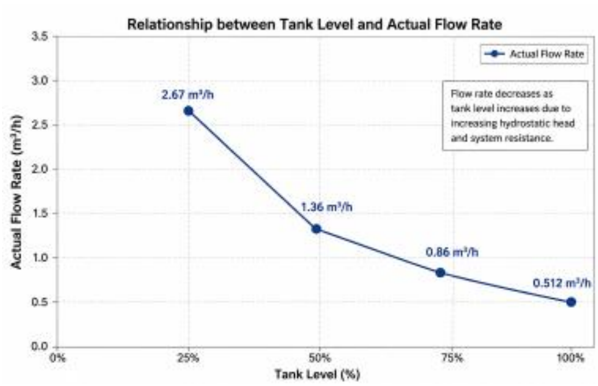

Fig. 4. Relationship between tank level and actual flow rate.

The actual flow rate decreased from 2.67 m^3/h at the 25% tank level to 0.512 m^3/h at the 100% level. This reduction occurred because the hydrostatic head continuously increased during the filling process, resulting in a higher system resistance and a lower pump discharge capacity. Consequently, the pump operating point shifted toward a lower flow region.

B. Head Loss Analysis

The major head loss, minor head loss, and total head loss were calculated using the Darcy–Weisbach equation and minor loss coefficients for each piping component. The comparison of head losses at different filling levels is presented in Fig. 5.

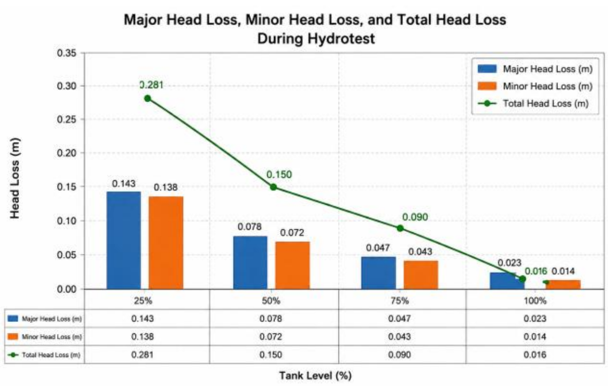

Fig. 5. Major head loss, minor head loss, and total head loss during hydrotest.

The calculated total head loss ranged from 0.281 m at the beginning of filling to 0.016 m at the final level. Both major and minor losses decreased as the flow rate decreased. Compared with the hydrostatic head, the total head loss was relatively small, indicating that piping losses had only a minor influence on the overall system performance.

C. Hydrostatic Head and Total Dynamic Head

The hydrostatic head increased proportionally with the water level inside the tank, while the Total Dynamic Head (TDH) remained relatively constant throughout the hydrotest process. The variation of hydrostatic head and TDH is shown in Fig. 6.

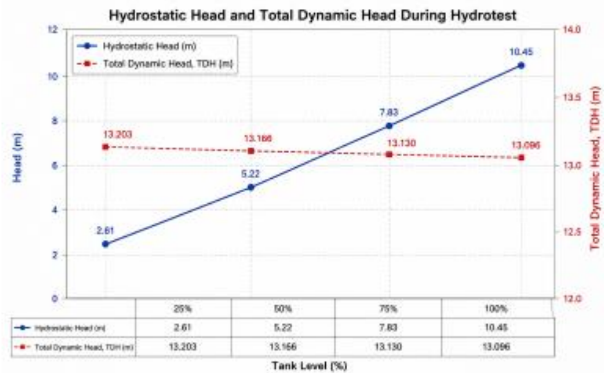

Fig. 6. Hydrostatic head and Total Dynamic Head during hydrotest.

The hydrostatic head increased from 2.61 m to 10.45 m, whereas the TDH remained within 13.096–13.203 m. Although the hydrostatic head increased significantly, the reduction in friction losses compensated for part of the additional system head, resulting in only a slight variation in TDH.

D. Pump Power Analysis

Hydraulic power and pump power were calculated based on the actual flow rate and Total Dynamic Head. The calculated pump performance is illustrated in Fig. 7.

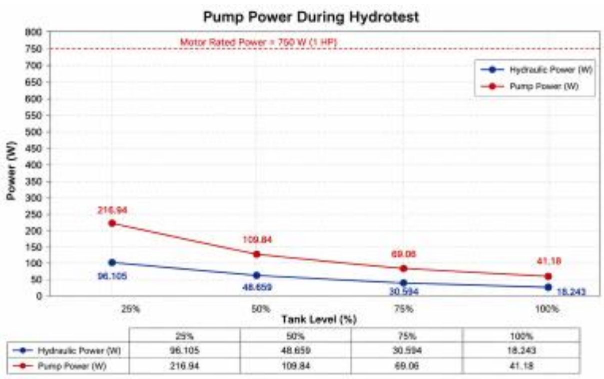

Fig. 7. Hydraulic power and pump power during hydrotest.

The hydraulic power decreased from 96.105 W to 18.243 W, while the pump power decreased from 216.94 W to 41.18 W as the tank level increased. This trend was mainly caused by the continuous reduction in actual flow rate. The calculated pump power remained significantly lower than the motor rated power of 750 W (1 HP), indicating that the pump operated safely without overload during the hydrotest.

E. Filling Time and Hydrotest Performance

The filling time for each tank level increased significantly throughout the hydrotest process. The comparison of filling time at each stage is presented in Fig. 8.

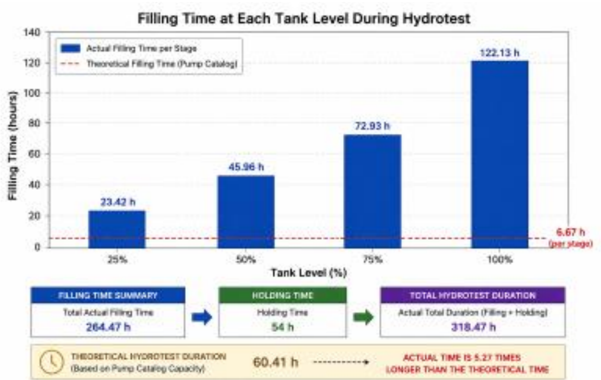

Fig. 8. Filling time at each tank level.

The filling time increased from 23.42 h at the first filling stage to 122.13 h at the final stage. The total actual filling time reached 264.47 h, and after including the 54 h holding time, the total hydrotest duration became 318.47 h. Compared with the theoretical hydrotest duration of 60.41 h based on the pump catalog capacity, the actual process required a substantially longer time due to the continuous decrease in actual flow rate.

F. Discussion on Hydrotest System Performance

The results demonstrate that the increase in hydrostatic head was the dominant factor affecting the hydrotest performance. As the water level increased, the hydrostatic pressure imposed a greater resistance on the pumping system, causing the actual flow rate to decrease continuously. Although the piping configuration generated friction losses, the calculated head losses were relatively small compared with the hydrostatic head.

The prolonged hydrotest duration was therefore primarily attributed to the reduction in pump flow capacity under actual operating conditions rather than to piping friction losses. In addition, the top-filling configuration, free-discharge system, and long discharge hose contributed to the difference between the actual operating condition and the pump manufacturer's standard performance curve.

The findings indicate that improving the hydrotest system should focus on optimizing the pumping configuration, maintaining a stable suction pressure, and selecting a pump with characteristics that better match the actual system head to reduce hydrotest duration.

IV. CONCLUSION

This study analyzed the actual performance of a 250 m³ SS316L storage tank hydrotest system using a centrifugal pump under actual field operating conditions.

The actual flow rate continuously decreased from 2.67 m^3/h to 0.512 m^3/h as the hydrostatic head increased from 2.61 m to 10.45 m during the filling process. The calculated total head loss remained relatively small (0.281–0.016 m), indicating that piping friction had only a minor influence on the overall system performance.

The Total Dynamic Head (TDH) remained relatively constant within 13.096–13.203 m, while the hydraulic power and pump power decreased from 96.105 W to 18.243 W and 216.94 W to 41.18 W, respectively, following the reduction in actual flow rate.

The total actual filling time reached 264.47 h, and the overall hydrotest duration became 318.47 h after including the holding time, which was substantially longer than the theoretical duration of 60.41 h calculated from the pump catalog capacity.

Overall, the study concludes that the increase in hydrostatic head is the primary factor responsible for the reduction in actual flow rate and the extension of hydrotest duration, whereas piping head loss has only a limited effect on the overall hydrotest system performance.

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