iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: VII Month of publication: July 2025

DOI: https://doi.org/10.22214/ijraset.2025.73307

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VII July 2025- Available at www.ijraset.com

Design Optimization of Cooling System for a Tractor Engine Using Ethylene Glycol-Water Base Fluid

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Abstract: An experimental study was conducted to evaluate the thermal performance of a tractor diesel engine cooling system using a 50:50 ethylene glycol (EG)–water coolant. The objective was to characterize how cooling parameters vary with engine operating conditions. A tractor engine was coupled to a dynamometer and cooled by a radiator in a closed loop. Temperatures, flow rate, engine speed, exhaust losses, and brake power were measured. Results show that the coolant temperature drop across the radiator remained nearly constant (~3°C) over 1000–2000 rpm. Exhaust heat loss rose nearly linearly with speed (from ≈13 kW at 1000 rpm to ≈32 kW at 2000 rpm), indicating more waste heat at higher loads. Brake thermal efficiency peaked at about 37.5% around 1400 rpm, then declined at higher speeds, consistent with increased heat and friction losses. Flywheel power reached ≈41 kW at 1800 rpm and plateaued. Increasing coolant flow rate elevated the convective heat-transfer coefficient and heat removal rate. In summary, the cooling system-maintained engine temperature effectively, with best performance in the mid-RPM range. The 50:50 EG–water mixture provided adequate heat rejection, but its ~20% lower heat capacity requires slightly higher flow (≈15–20%) than pure water.
Keywords: Engine cooling; Radiator heat transfer; Ethylene glycol; Tractor engine; Thermal efficiency; Convective coefficient; Cooling system performance.

I. INTRODUCTION

The advancement of agricultural machinery, particularly tractors, necessitates improved thermal management to maintain performance and durability under varying operating conditions. In rural and agricultural environments, tractors often operate continuously for long durations in dusty, hot climates, which puts significant strain on the engine's thermal system. Therefore, understanding and improving the thermal efficiency of the cooling system becomes essential not only for engine protection but also for reducing fuel consumption and enhancing operational lifespan[1], [2], [3]. Cooling systems in diesel engines are responsible for dissipating the heat generated from combustion to avoid overheating. When the heat generated exceeds the cooling system's capacity to dissipate it, it can result in thermal fatigue, component failure, and reduced lubrication efficiency[4], [5], [6]. This leads to decreased engine efficiency and increased maintenance cost[7], [8], [9]. Hence, optimizing the cooling system by selecting appropriate fluids, improving flow dynamics, and designing effective heat exchangers is a vital area of research[10]. Conventional coolants include water, which has a high specific heat capacity, making it effective for absorbing heat. However, water's freezing and boiling points limit its applicability, especially in extreme weather conditions[11]. Ethylene glycol (EG) is added to water to overcome these limitations. The EG-water mixture has desirable thermophysical properties such as lower freezing point, higher boiling point, and corrosion inhibition. Despite a lower specific heat than water, a 50:50 EG-water mixture is commonly used due to its balanced thermal and protective characteristics[12], [13], [14]. Tractor engine cooling performance is affected by several parameters, including coolant type, coolant flow rate, radiator design, engine load, and ambient temperature. To ensure robust thermal regulation, these parameters must be tuned effectively. Past research has shown that engine load and RPM have direct correlations with exhaust gas temperature, heat rejection, and efficiency[15]. Yet, real-world experimental validation under controlled conditions is necessary to tailor these insights to specific engine types, such as those used in agricultural tractors.

This study focuses on investigating the thermal behavior of a tractor diesel engine using a 50:50 EG-water coolant blend. By evaluating coolant temperature drop, exhaust losses, flywheel power output, and convective heat transfer characteristics, this work aims to provide a comprehensive understanding of the engine's cooling response to RPM variation. The findings can assist in identifying optimal design configurations for radiator sizing, coolant selection, and pump specification, which are key to improving the overall performance and reliability of agricultural engines[16].

Efficient cooling is critical in tractor engines because most of the fuel energy is rejected as heat. Only about 30–40% of the fuel's energy is converted to useful work; the remainder is lost mainly as heat through the exhaust and through heat transfer to the coolant. A robust cooling system prevents overheating and ensures reliable operation under heavy load and varying ambient conditions. The importance of engine cooling in agricultural tractors is even more pronounced due to their extended duty cycles and operation in thermally challenging environments, such as under direct sunlight and during heavy tillage. Overheating not only affects engine performance and fuel economy but can also lead to lubricant breakdown, premature wear, head gasket failure, and other severe consequences. Therefore, the design optimization of the cooling system is central to enhancing engine life and maintaining operational reliability[17]. In internal combustion engines, the heat generated during combustion is dissipated through three primary routes: exhaust gases, coolant fluid, and surface convection from components. While exhaust losses are inevitable, the engine's thermal control depends largely on the efficiency of the radiator and coolant flow system. A typical cooling system consists of the radiator, water pump, thermostat, cooling fan, and connecting hoses. The choice of coolant is also a key design consideration. Pure water, although having high specific heat, has freezing and boiling limitations. Ethylene glycol-based coolants overcome this by lowering the freezing point and raising the boiling point. A 50:50 EG–water blend is widely used in the automotive and agricultural sectors due to its balance between thermal performance, freeze protection, and corrosion inhibition. The use of EG–water mixtures requires revaluation of system parameters such as flow rate, pump design, and radiator sizing due to its altered physical properties, especially lower specific heat and higher viscosity than water. These changes influence heat transfer characteristics and pressure drop across the radiator. Moreover, understanding how engine RPM affects the cooling system's performance metrics such as temperature drop, convective coefficient, and efficiency is vital for system optimization[18].

This research aims to experimentally assess the cooling characteristics of a typical tractor diesel engine operating with a 50:50 EG–water mixture, across varying engine speeds. The study not only analyzes coolant temperature drop and heat rejection performance but also explores the interaction between engine efficiency, exhaust heat loss, and flywheel output. The ultimate objective is to identify the optimal RPM range for thermal efficiency while ensuring reliable cooling performance, thereby contributing to the broader goal of design optimization of tractor cooling systems.

II. SAMPLE PREPARATION

The coolant used in this study was a mixture of ethylene glycol and distilled water in equal volume proportions (50:50). Ethylene glycol was chosen for its antifreeze properties, higher boiling point, and ability to inhibit corrosion. Distilled water was used to avoid scaling and mineral deposit issues[19]. The mixture was prepared by measuring equal volumes using calibrated containers and thoroughly mixing to ensure homogeneity. The physical properties of the coolant at operating temperatures (~90–100°C) included a density of approximately 1077 kg/m³ and specific heat capacity of ~3.4 kJ/kg·K. These values were referenced during heat transfer calculations[20], [21], [22], [23], [24].

III. DATA REDUCTION

The rate of heat transfer through convection is governed by a fundamental principle known as Newton's Law of Cooling. This law states that the rate of heat transfer is proportional to the temperature difference between the object and its surroundings [25].

$$\dot{Q}_c = h\,A\,\Delta T \quad (W) \tag{1}$$

Here, $\dot{Q}_c$ (W) The convective heat transfer rate between the exposed wall surface and the radiator is represented, while (T_s) (°C) indicates the surface temperature of the radiator. Laser thermometers are used to measure the radiator surface temperature in order to improve accuracy. The radiator's exterior is segmented into four symmetrical portions, with individual temperature measurements taken at each section's centre.

The radiator's surface temperature is calculated by averaging four measured values. The room temperature, indicated as Tr (°C), and the convective heat transfer coefficient, denoted as h (W/m²°C), are affected by factors such as fluid flow, the fluid's thermal properties, and the system's physical geometry and orientati on where convection occurs. The convection coefficient varies based on where the fluid's temperature is measured and isn't uniform across the entire surface. Typically, the average convection coefficient value is used. For vertical isothermal walls, the convection coefficient can be determined using the Nusselt number, as expressed in Eq. (2) [25], [26].

$$\overline{Nu} = \frac{\bar{h}l}{k} = C\,Ra^n \rightarrow \bar{h} = \frac{Ck}{l} Ra^n \tag{2}$$

The heat transfer rate on the hot fluid side, along with the air side, is modelled to evaluate the overall heat transfer performance of the system.

$$\mathbf{Q = mC_P(T_o - T_i)} \quad (W) \tag{3}$$

The forced convective heat transfer between a heated fluid and a surface is governed by Newton's law of cooling, as detailed in Equation (4).

$$\mathbf{Q = hA(T_o - T_i)} \quad (W) \tag{4}$$

The hydraulic diameter must be used if cross-sectional area is not circular, the hydraulic diameter is calculated as

$$D_h = \frac{\mathbf{4A}}{\mathbf{P}} \quad (m) \tag{5}$$

$$u = \frac{\mathbf{Q_{fx}}}{\mathbf{NA_{tube}}} \tag{6}$$

The hydraulic diameter is utilized to determine both the Nusselt number and the Reynolds number. The heat transfer rate of the entire section on the air side is

$$\mathbf{Q_a} = \mathbf{m_a C_{p.a}}\,(\mathbf{T_{ao}} - \mathbf{T_{ai}}) \quad (W) \tag{7}$$

The forced convective heat transfer between air and a surface can be explained using Newton's law of cooling, as shown in Equation (4).

$$\mathbf{Q_a} = \mathbf{h_a} A\,(\mathbf{T_w} - \mathbf{T_{b.a}}) \quad (W) \tag{8}$$

The rate of heat carries over between nano-fluid coolant and air flow in the automobile radiator is as follows

$$Q = \mathbf{m_{nf} C_{p.nf}(T_{nfo} - T_{nfi})} = \mathbf{m_a C_{p.a}(T_{ao} - T_{ai})} \quad (W) \tag{9}$$

The Nusselt number for fully developed laminar flow was determined for a rectangular cross section. It is used to calculate the width over height ratio of the tube [25].

IV. METHODOLOGY

The experimental setup consisted of a tractor diesel engine mounted on a test stand with its cooling loop connected to a radiator and measuring instruments. Figure 1 shows the engine and radiator assembly used in the experiment. A single-cylinder (approx. 35–40 kW) 4-stroke diesel engine was driven by a hydraulic dynamometer to control load and speed. The cooling system included the engine block cooling jackets, a centrifugal coolant pump, a crossflow radiator, and an overflow reservoir. Engine speed (1000–2000 rpm range) was set by adjusting dynamometer load. Coolant flowed from the reservoir into the pump, through the engine jacket, then through the radiator core, and back, driven by the pump. Thermocouples were installed at the radiator inlet and outlet, and also in the exhaust manifold, to record fluid and exhaust temperatures. Flywheel torque and speed were measured by the dynamometer to calculate output power. Fuel consumption was measured with a flow meter to compute brake thermal power. This instrumentation allowed calculation of thermal power removed by the radiator and efficiency of the engine. The radiator was a standard tractor radiator with a finned-tube core, as illustrated in Figure 2. Coolant flow rate was measured by an in-line flow meter. An electric fan provided airflow, though its effect was secondary to engine-driven flow under the test conditions. The 50:50 ethylene glycol–water coolant was prepared by mixing pure EG with distilled water to prevent scaling or ionic impurities. The coolant's properties at operating temperature were in line with published values (density ≈1077 kg/m³, cp ≈3.4 kJ/kg·K for 50% EG).

Measurements and instrumentation in the experiment included:

1) Engine speed (rpm): Tachometer on the dynamometer
2) Coolant temperature drop (ΔT): Difference between radiator inlet and outlet
3) Exhaust gas temperature: Thermocouple in exhaust manifold
4) Exhaust heat loss (kW): From measured exhaust flow rate and temperature rise
5) Flywheel power (kW): Dynamometer output (torque × speed)
6) Fuel consumption: Mass flow to compute fuel energy input
7) Brake thermal efficiency (%): Ratio of brake power to fuel energy input
8) Coolant flow rate: Flow meter in loop
9) Radiator heat transfer rate (kW)
10) Convective heat transfer coefficient (h)

All experiments were conducted after achieving steady-state conditions. The coolant flow rate was varied in separate trials to obtain data for convective coefficient versus flow rate. Data were recorded for a range of engine speeds.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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Figure 1 Tractor engine and radiator assembly used in the experiment.

Figure 2 Side view of the radiator and coolant plumbing.

V. RESULTS AND DISCUSSION

A. Coolant Temperature Drop vs. RPM

Figure 3 shows the variation of coolant temperature drop across the radiator with increasing engine RPM. The coolant temperature drop (ΔT) across the radiator remained small, typically ranging between 2.7–3.5°C over the engine speed range of 1000 to 2000 RPM. A peak temperature drop of approximately 3.5°C was recorded at 1200 RPM, while the lowest (2.7°C) occurred at 1400 RPM. This consistency implies efficient heat removal by the radiator, confirming its capability to maintain stable engine temperatures even as RPM increased.

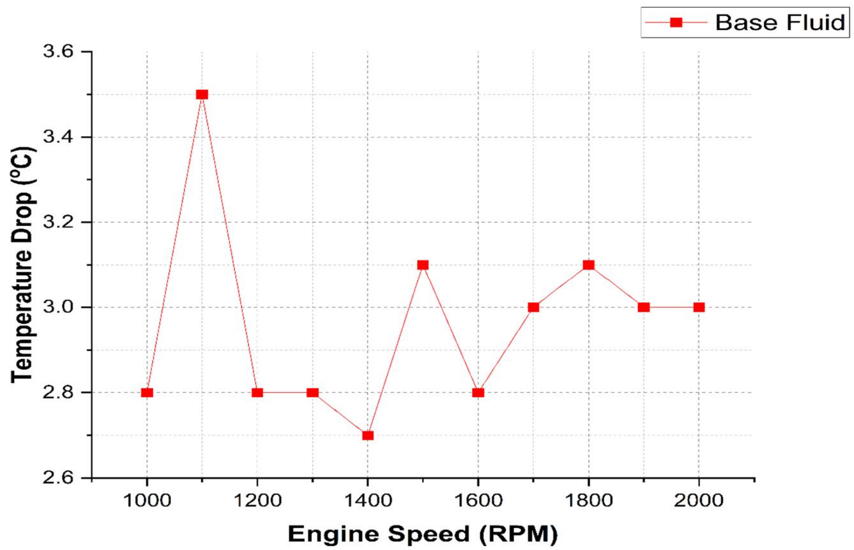

Figure 3 Coolant Temperature Drop vs. Engine Speed.

B. Thermal Power Lost Through Exhaust Gas vs. RPM

As presented in Figure 4, the thermal power lost through exhaust gas increased steadily with engine RPM. The thermal power lost through the exhaust gas increased progressively with engine speed, from about 13 kW at 1000 RPM to over 32 kW at 2000 RPM. This linear trend reflects higher combustion intensity and fuel usage at elevated RPMs, leading to greater thermal losses. This data supports the necessity of a robust cooling mechanism to offset rising exhaust heat at high speeds.

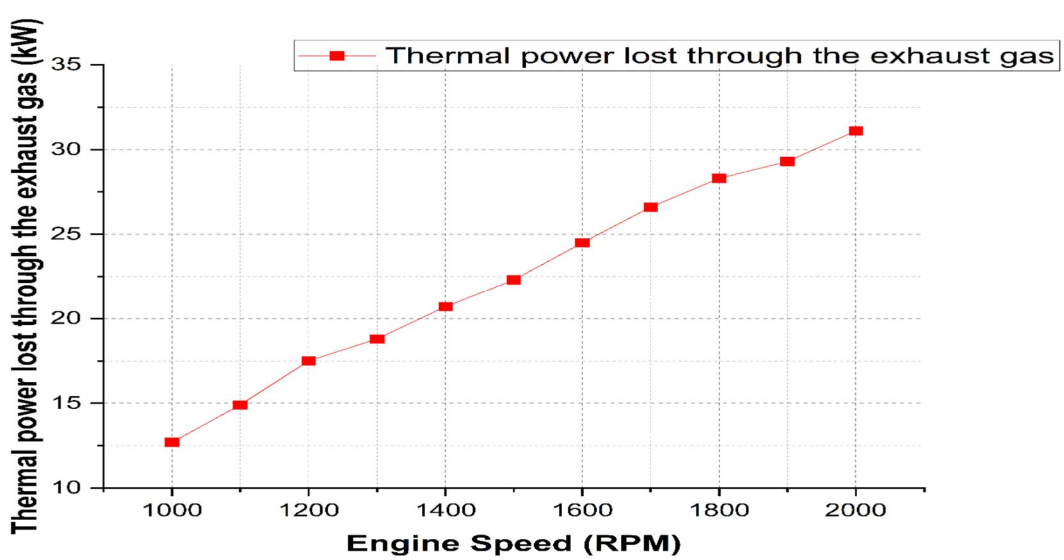

Figure 4 Thermal Power Lost Through Exhaust Gas vs. Engine Speed.

C. Engine Efficiency vs. RPM

The brake thermal efficiency of the engine, illustrated in Figure 5, reveals a parabolic trend peaking around 1400 RPM. Engine brake thermal efficiency rose to a maximum of 37.5% at 1400 RPM and then declined slightly beyond that point. Efficiency was lowest (around 35.3%) at 2000 RPM due to increased thermal and frictional losses. The engine achieved optimal performance in the mid-range speeds, highlighting this zone as the most effective operational window for both fuel economy and thermal management.

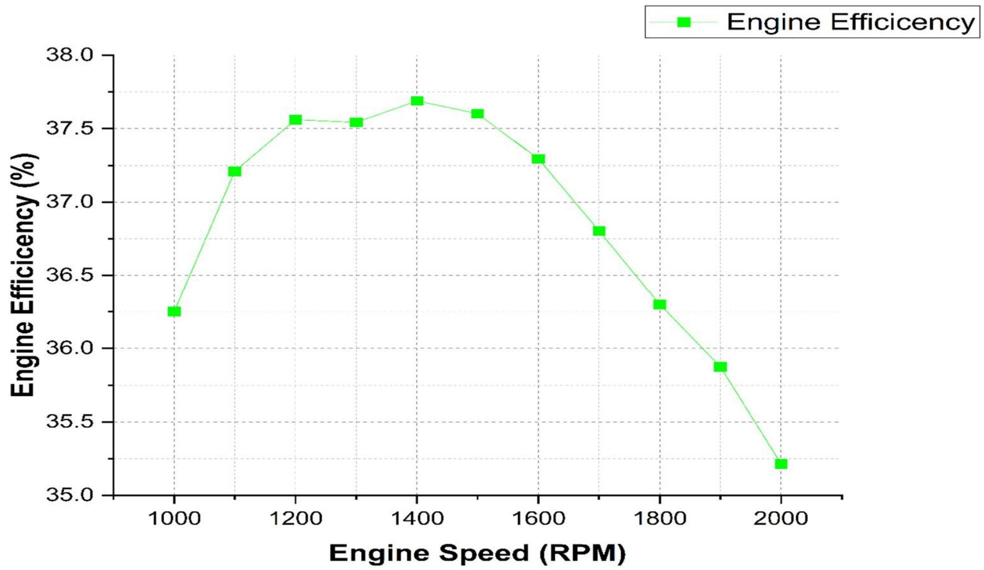

Figure 5 Engine Efficiency vs. Engine Speed.

D. Flywheel Power vs. RPM

The flywheel power trend is shown in Figure 6, where a steady increase is observed up to 1800 RPM, after which it stabilizes. Flywheel (brake) power rose with engine speed, peaking at approximately 41 kW at 1800 RPM before leveling off. This reflects the engine's torque characteristics and indicates that further increases in speed yield diminishing returns in power output.

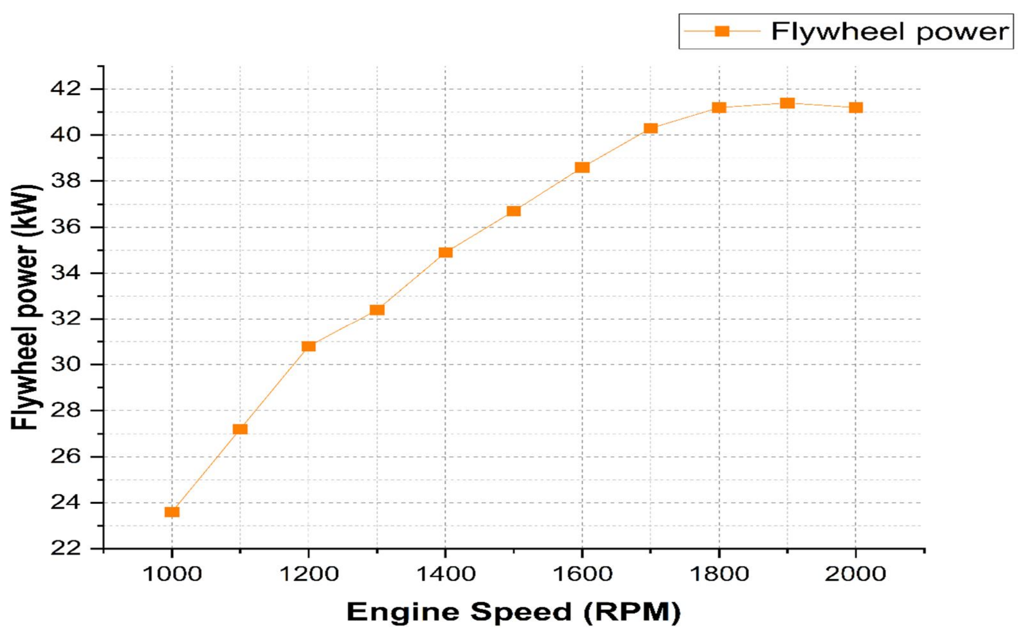

Figure 6 Flywheel Power vs. Engine Speed.

E. Convective Heat Transfer Coefficient vs. Coolant Flow Rate

Figure 7 plots the convective heat transfer coefficient as a function of coolant flow rate.

A positive linear relationship was observed between coolant flow rate and the convective heat transfer coefficient. As flow increased from 75 to 150 LPM, the coefficient rose from about 27,000 to over 46,000 W/m²·K. This confirms that increased turbulence and velocity at higher flows significantly enhance convective heat removal.

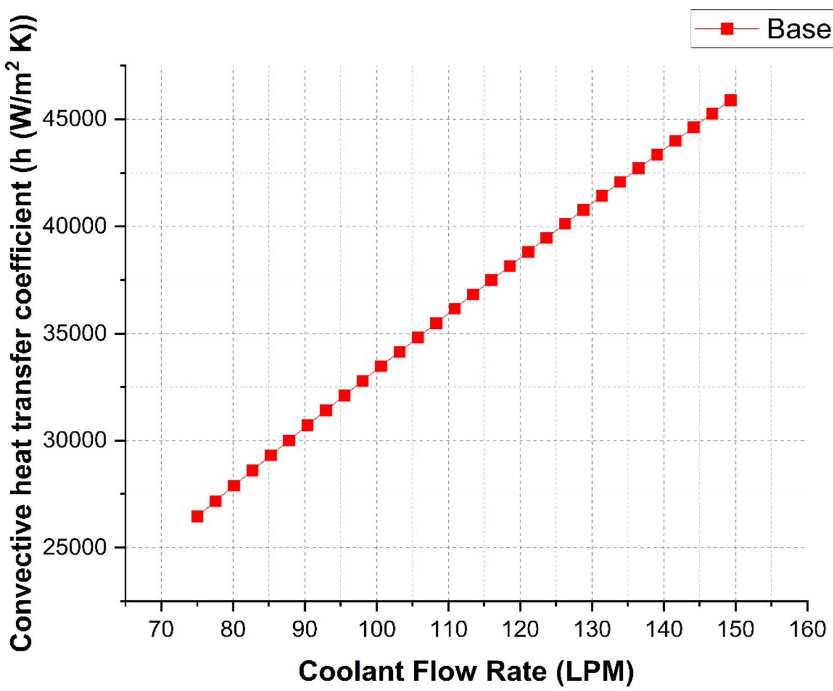

Figure 7 Convective Heat Transfer Coefficient vs. Coolant Flow Rate.

Heat Transfer Rate vs. Coolant Flow Rate

Figure 8 illustrates the corresponding increase in total heat transfer rate with rising coolant flow rate. Similarly, the total heat transfer rate increased with coolant flow rate. At lower flows, rates were around 14,000–18,000 W, whereas flows above 120 LPM consistently exceeded 26,000 W. The highest heat transfer rate reached approximately 30,000 W at 150 LPM, validating the effectiveness of higher flow in improving radiator performance.

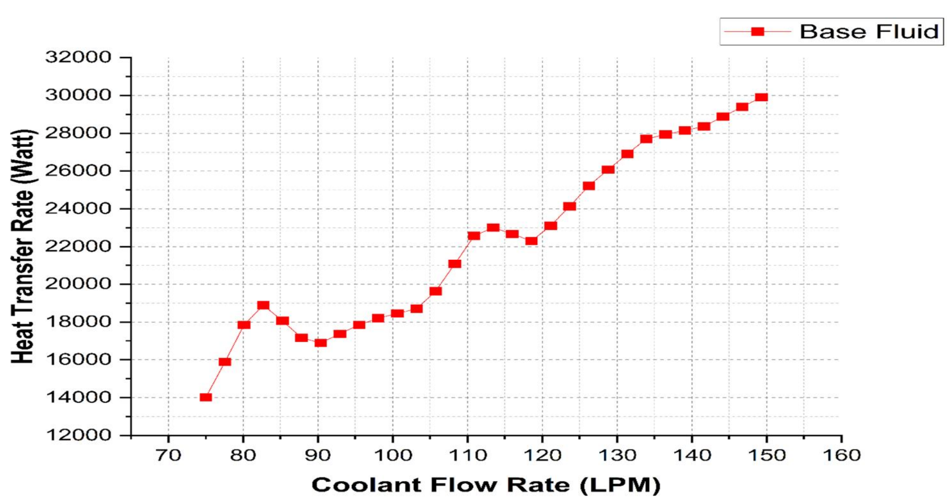

Figure 8 Heat Transfer Rate vs. Coolant Flow Rate.

F. Thermal Power Exchanged Through Radiator vs. RPM

The performance of the radiator in dissipating thermal power with respect to engine speed is captured in Figure 9. Thermal power exchanged through the radiator ranged from around 13 kW at 1000 RPM to nearly 28 kW at 2000 RPM. These results closely tracked exhaust thermal losses, indicating that the cooling system successfully absorbed and dissipated the increasing thermal load at higher speeds.

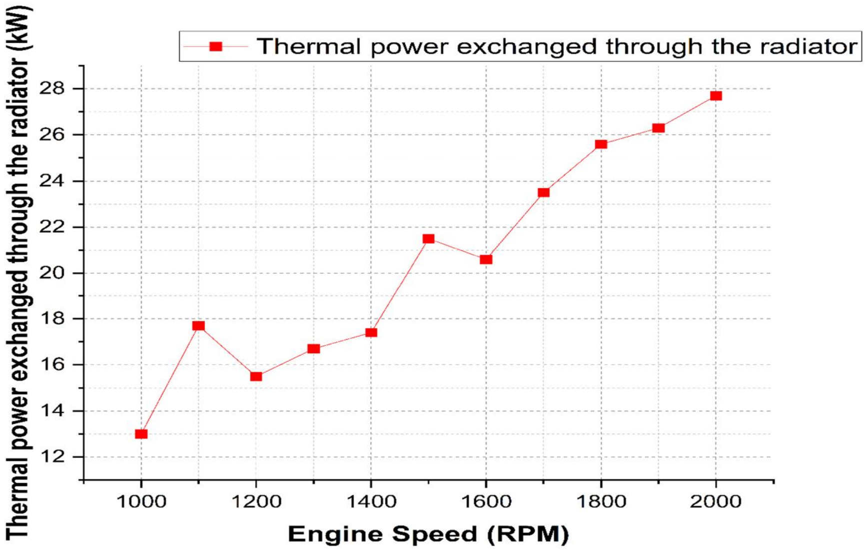

Figure 9 Thermal Power Exchanged Through Radiator vs. Engine Speed.

G. Exhaust Gas Temperature vs. RPM

As shown in Figure 10, the exhaust gas temperature exhibits a gradual increase with engine RPM. The exhaust gas temperature also followed an increasing trend with engine RPM, ranging from 455°C at 1000 RPM to nearly 480°C at 2000 RPM. This parameter further supports the growing heat generation within the engine and emphasizes the necessity for reliable exhaust and coolant heat dissipation systems.

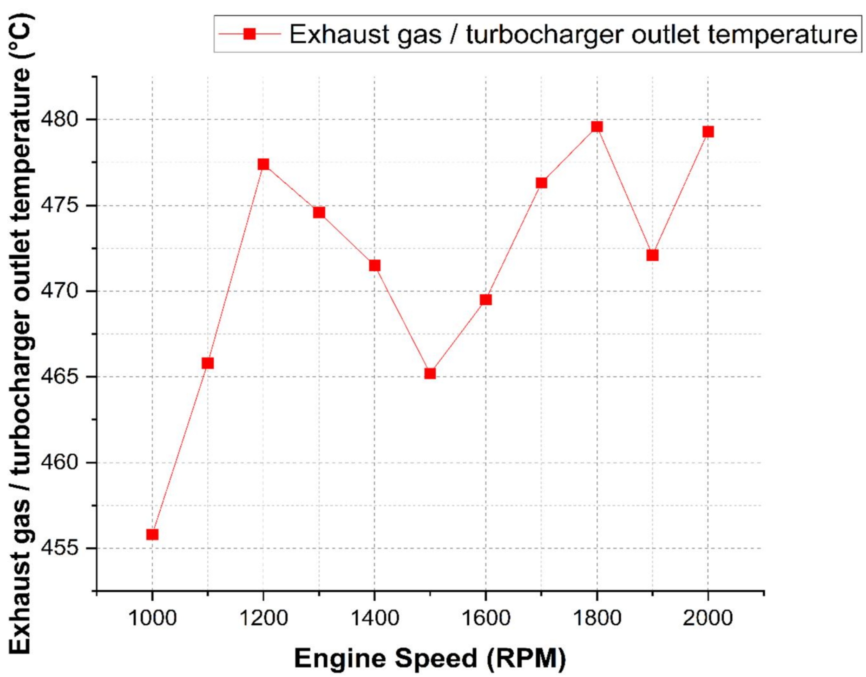

Figure 10 Exhaust Gas / Turbocharger Outlet Temperature vs. Engine Speed.

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ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VII July 2025- Available at www.ijraset.com

VI. CONCLUSION

This experimental analysis on a tractor diesel engine cooling system using a 50:50 ethylene glycol-water mixture demonstrated the system's efficiency across a wide RPM range. The results showed that while flywheel power and exhaust heat increase with engine speed, the radiator was capable of maintaining effective thermal performance, with only minor changes in coolant temperature drop.

1) The study verified that brake thermal efficiency peaked at around 1400 RPM, indicating this range as optimal for balancing power output and heat rejection. At this point, the engine operated with the highest efficiency and minimal thermal stress. Additionally, the exhaust gas temperatures and power losses tracked engine RPM closely, which validates the cooling system's ability to scale with thermal demand.
2) The results showed that as coolant flow rate increased, the convective heat transfer coefficient and the heat transfer rate also increased, confirming that forced convection plays a dominant role in thermal management. This implies that by optimizing pump performance and coolant flow paths, one can significantly improve the cooling efficiency of the system.
3) Furthermore, the study reinforces that despite the slightly lower specific heat of ethylene glycol-based coolants, they are highly effective when used in the correct ratio with water. The additional benefits such as freeze protection, anti-corrosion properties, and higher boiling point make them ideal for harsh agricultural conditions.

In conclusion, this research highlights the importance of cooling system optimization in improving engine durability and performance in tractors. Future scope includes incorporating nanofluid additives, adaptive flow control systems, and CFD-based design tools to further enhance cooling performance under dynamic operating conditions.

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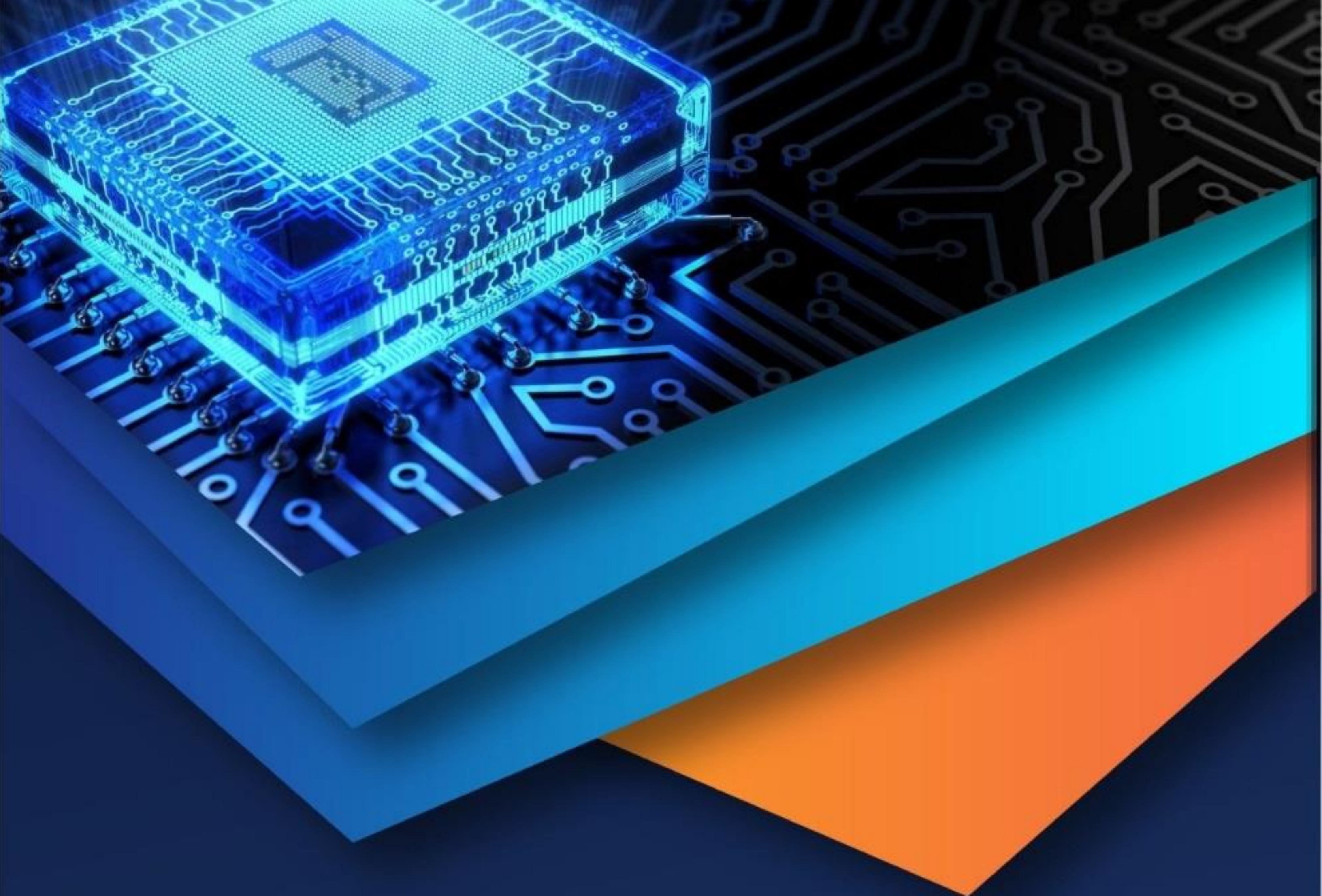

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