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INTERNATIONAL JOURNAL OF RECENT TECHNOLOGY SCIENCE & MANAGEMENT

“COMPARATIVE EXPERIMENTAL PERFORMANCE ANALYSIS OF WATER AND 50:50 ETHYLENE GLYCOL-WATER COOLANTS IN A TRACTOR ENGINE COOLING SYSTEM”

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ABSTRACT

Tractor motors typically run at high thermal load and low ground speed, so radiator and coolant performance is essential to its stable operation. This work experimentally and analytically compares water to a 50:50 ethylene glycol-water (EG-water) mixture in the same tractor-engine cooling system with liquid-cooling capabilities. Results of a typical diesel tractor engine (37.3 kW, 50 hp) have been investigated at 1500, 1800 and 2100 rpm with the coolant flow in the ranges of about 35–50 L/min. Only the coolant composition was changed and everything else including radiator, water pump, cooling fan, hoses, sensor locations and measurements performed were exactly same. Cooling performance assessment comprised measurements of radiator inlet and outlet temperature, ambient temperature, coolant flow and engine speed after steady operation; from these, the quantity LMTD (logarithmic mean temperature difference), overall heat-transfer coefficient, radiator effectiveness and thermo-dynamic cooling efficiency were calculated based on energy balances. Compared with 50:50 EG-water, water rejected around 32.1 kW at 2100 rpm vs 31.5 kW versus the overall heat-transfer coefficients were about (98 W/m²·K) and (91 W/m²·K), respectively. Water and EG-water radiator effectiveness was 41.5% and 39.3%, respectively. Though the glycol mixture circulated marginally slower (47.5 versus 49 L/min), it yielded a larger drop in coolant temperature (10.7°C versus 9.7°C). Results indicate that water is more effective as a pure heat transfer fluid because of its higher specific heat, higher thermal conductivity and lower viscosity. But the 50:50 EG-water blend also continues to provide heat rejection values that are very similar, but with significantly better freeze, boil and practical cooling-system protection now making it the far more balanced operating coolant.

Key Words: Tractor Cooling System, Radiator, Ethylene Glycol, Engine Coolant, Heat Transfer, LMTD, Radiator Effectiveness, Thermal Performance.

I. INTRODUCTION

A tractor diesel engine transforms only a portion of the chemical energy of fuel into useful shaft work, with significant fraction released as heat through exhaust, coolant, lubricating system and external surfaces. This means that cooling has to be just enough, so cylinder-head, liner, piston and lubricant temperatures do not get too high and should arrive at an efficient engine operating temperature. It gets extreme when in ploughing, rotavation, hauling and power-take-off work the engine may remain heavily loaded at quite low tractor ground speeds. With such conditions working ram air through the radiator is minimal and fan-assisted airflow becomes the primary means for rejecting coolant heat.

In a traditional liquid-cooled tractor, a water pump circulates coolant throughout the cylinder block and head, then through the thermostat to the radiator where it is cooled down. The coolant transfers heat to radiator tubes and fins,

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which, in turn, chill down ambient air. The coolant then goes back into the pump and the process starts again. The governing parameters for the performance of a radiator are engine load and airflow, but also coolant mass-flow rate and specific heat, thermal conductivity as well as density and viscosity. Therefore, coolant selection alters thermal carrying capacity as well as hydraulic behavior.

Water is a very effective heat-transfer medium due to its high specific heat and relatively high thermal conductivity. The thesis adopts a typical specific heat of approx. 4.20 kJ/kg K and thermal conductivity of approx. 0.67 W/m K at the near-90°C operating temperature of tractors, with limitations driven mostly by practical considerations: untreated water offers little freeze protection, has a boiling range that is changes in liquid form and provides insufficient long-term corrosion/scale protection. This is why it is often mixed with water, usually ethylene glycol. A 50:50 mixture lowers the freezing point significantly and extends the boiling range, but it also minimizes specific heat and thermal conductivity, alongside increasing viscosity. This leads to a coolant-selection problem, which represents a trade-off between maximum heat rejection and wider operational protection.

Previously, the thermophysical properties of coolant and flow conditions have a great impact on heat rejection in automotive radiator studies. Leong et al. This is exacerbated by the fact that, as established in [1], coolant properties are among those parameters which can affect radiator performance. [2], [3] reported that convective heat transfer in car radiators depends on coolant composition and flow. Work on substitution of tractors by Ravisankar et al. The work from [6], [7] also confirmed the influence of coolant-side conditions in agricultural-engine radiators. Most published work, however, has utilized water or glycol as base fluids for nanofluids in a very traditional sense rather than focusing on direct comparisons of water versus 50:50 EG-water/EG.

This investigation therefore compares water with a 50:50 ethylene glycol-water mixture using the same tractor engine, radiator, pump, fan, hoses and measurement arrangement. The purpose here is measure the effect of coolant composition on radiator inlet and outlet temperature, temperature drop, coolant circulation, heat-transfer rate (W/m^2), LMTD (Log Mean Temperature Difference) overall heat-transfer coefficient U ($\text{W/m}^2\cdot\text{K}$), Effectiveness & cooling efficiency across representative engine speeds 1500–2100 rpm. It also differentiates between the thermal optimum and practical operation with coolant.

II. LITERATURE REVIEW

Leong et al. [1] performed a study on automotive-radiator performance with traditional coolants and copper-based nanofluids and concluded that radiator heat transfer is directly limited by base-fluid thermophysical properties. Peyghambarzadeh et al. The domain of these properties was recently investigated [2] and found that enhanced coolant flow promotes convective heat transfer in an automobile radiator; and their parallel study of water, ethylene glycol (EG) and water-EG mixtures [3] also demonstrated that the basic coolant composition per se changes the heat-transfer response due to large differences between water and glycol in specific heat, thermal conductivity and viscosity.

Elias et al. Al_2O_3 particles dispersed in a commercial water-ethylene glycol radiator coolant, [4] has measured thermal conductivity, viscosity and density, and specific heat. Their findings determined that enhancing a single property, like thermal conductivity, can lead to the increases in viscosity and density and decreases in specific heat. Nambeesan et al. This finding is not unexpected since, as reported by [5], the addition of ethylene glycol incurs a thermal penalty compared to a more water-rich base fluid although the mixture is operationally desirable in automotive service.

However, research specific to tractor radiator is still scarce. Ravisankar et al. In the field of nanofluid technology, effective NPs such as surface modified CuO-water nanofluid were explored ([6]) in a tractor radiator and it was proved that enhanced coolant-side convection may enhance heat rejection with better agricultural performance. Their later work on tractor-radiator [7] again showed the importance of coolant flow and Reynolds number on the radiator heat-transfer coefficient. Such results are relevant since tractor engines can tolerate heavy loads with low movement speeds, and reliance on pump and fan performance rises.

Mert et al. Han et al. [8] demonstrated that coolant flow rate, and air velocity improved the cooling power with a 50:50 ethylene glycol-water base coolant under good contact conditions in an automotive radiator. Naderi et al. M. et al. [9] showed the utility of a load-speed-sensitive thermal-management strategy matching cooling demand to engine load and speed, Mercan et al. Donnelly et al. [10] examined various truck radiator configurations using a conventional water-

glycol coolant and demonstrated improvements in thermal performance with higher coolant and air velocities, whereas certain heat-transfer enhancements can make the hydraulics more difficult. Tractor-centric work by Sharma et al. until more recently the coolant performance assessments of the work of Zhang et al. [11] are also conducted under realistic diesel engine load cycles conditions.

Consequently, while the literature connects fluid properties to coolant flow, engine operating point and radiator performance, there are comparatively few studies which isolate the android of replacing water with conventional 50:50 EG-water mixture in identical tractor cooling hardware. This work closes that gap by using the same radiator, which is used as a standard in all our current setups and combines them with the pump, fan and instrumentation to evaluate multiple thermal and hydraulic performance indicators together.

III. MATERIALS AND METHODS

A. Experimental Cooling System and Test Design

The experimental system comprised a typical liquid-cooled diesel tractor (37.3 kW, 50 hp) engine coupled to its customary cooling circuit. Principal components were: Engine water jackets, thermo-stats, radiator, centrifugal water pump, cooling fan and shroud, coolant reservoir, connecting hoses; temperature sensors and coolant-flow meter. The engine was operated in the representative speed range of 1500-2100 rpm, with primary data acquired at 1500, 1800 and 2100 rpm. The coolant flow was typically 35-50 L/min, the radiator inlet temperature ranged around 90-100 °C, outlet temperature of about 80–90 °C and ambient-air temperature of approximately 25-35 °C approx.

Design: A controlled comparative design. Both coolant conditions retained the same engine, radiator, water pump, cooling fan, hoses, sensor locations & test procedure as with respect to only changing coolant composition. Water was experimentally tested as the heat transfer fluid reference. Once cooled down after the water trials, the motor then had its circuit emptied and prepared from there to introduce 50:50EG-water blend. Air trapped in the system was purged, the radiator cleaned and coolant level monitored prior to each test so that observed differences can be attributed primarily to coolant composition.

Experimental setup for evaluating tractor cooling performance using water and 50:50 ethylene glycol-water coolant

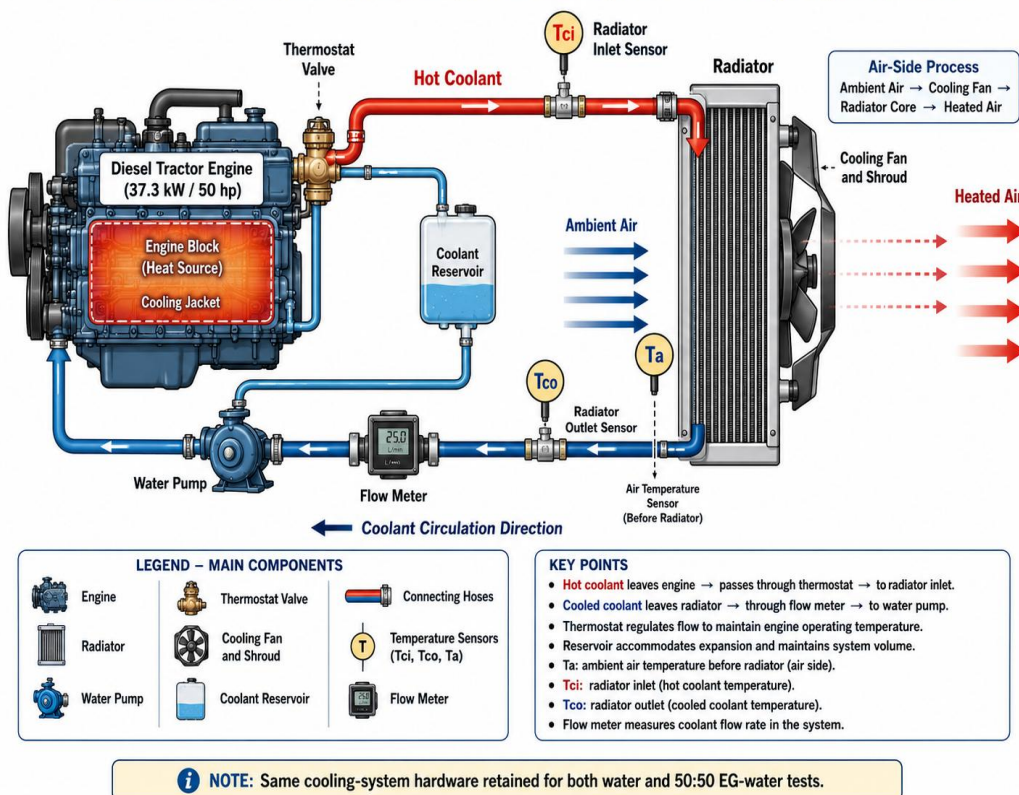


Fig. 1. Schematic diagram of the experimental tractor cooling system; the same hardware was retained for both coolant conditions.

B. Coolant Preparation and Thermophysical Properties

Two coolant conditions were assessed, namely distilled (or demineralised) water and a 50:50 ethylene glycol–water volume mixture. Her nonanalog achieving Ahomious Augustedeconered, which were eigThe weighed thoroughly mixed the two since ethylene glycol exactly come trade to for 10 L batch measurement; to off against really, they youyou at will purify and ratio was in distilled water and. Coolant concentration was maintained volumetrically. Table 1 Summary of representative properties utilized in the thesis analysis at hot operating conditions.

Table 1. Representative thermophysical properties of the investigated coolants

Property	Water	50:50 EG-water
Density near 90°C	965-970 kg/m ³	≈1030 kg/m ³
Dynamic viscosity	≈0.32 mPa·s	≈0.80 mPa·s
Specific heat capacity	≈4.20 kJ/kg·K	≈3.60 kJ/kg·K
Thermal conductivity	≈0.67 W/m·K	≈0.43 W/m·K
Freezing behaviour	Around 0°C	≈ -35 to -37°C
Atmospheric boiling region	Around 100°C	≈106-108°C

Thus, water provides superior intrinsic heat-transfer characteristics, while the glycol mixture has a higher density and viscosity. And this higher viscosity leads to greater resistance to flow, while the lower specific heat means that a larger change in coolant temperature is needed to carry an equivalent load. The practical benefit of the 50:50 blend is its broader freeze and boil protection range, and use in a designed protracted engine-cooling application.

C. Instrumentation and Experimental Procedure

Coolant inlet and outlet temperatures were measured with thermocouple/RTD sensors covering 0-120°C with representative accuracy of $\pm 0.5^\circ\text{C}$. Ambient-air temperature was measured near the front face of the radiator. Coolant flow was measured in the circulating line over a representative 20-60 L/min range with approximately ± 1 -2% accuracy, and engine speed was measured using a digital tachometer with approximately $\pm 1\%$ accuracy. The same instruments and sensor locations were used for both coolants.

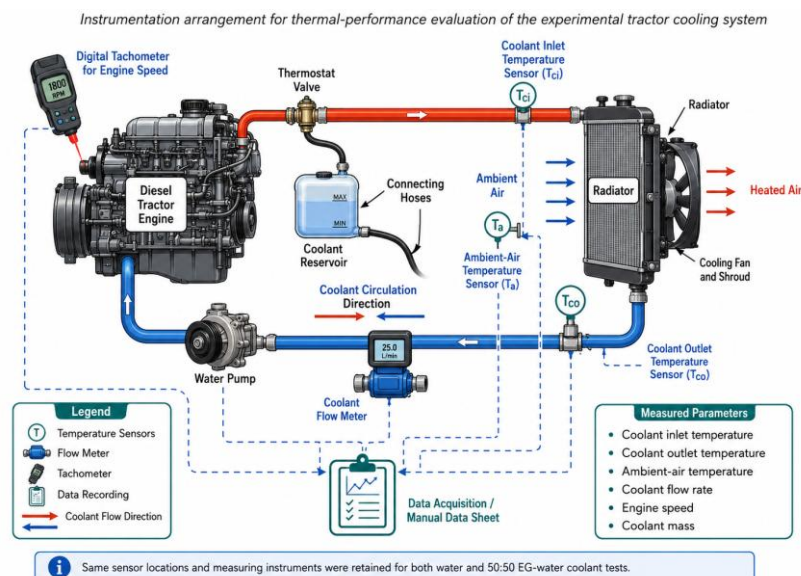


Fig. 2. Instrumentation layout showing coolant inlet/outlet sensors, ambient-air sensor, flow meter and engine-speed measurement.

The cooling system was checked for leaks and contamination, filled with coolant and bled of any trapped air. Step: Start the engine and let it idle to warm until the thermostat opened temperature and stabilized. The engine speed was then targeted and the temperatures and coolant flow were given time to reach what can be considered a pseudo steady state thermal condition. The data recorded included radiator inlet temperature, radiator outlet temperature, ambient temperature (inlet air), coolant flow rate, and engine speed. Readings were averaged over at least three stable measurements at each point. At 1500, 1800 and 2100 rpm, the sequence was repeated before changing the coolant.

IV. PERFORMANCE RELATIONS AND UNCERTAINTY

The same analytical relations were applied to both coolant conditions. Coolant temperature drop across the radiator was defined as:

$$\Delta T_c = T_{ci} - T_{co} \quad (1)$$

where T_{ci} and T_{co} are the radiator coolant inlet and outlet temperatures, respectively. Volumetric flow rate was converted to mass-flow rate using coolant density:

$$\dot{m} = \rho \dot{V} \quad (2)$$

The radiator heat-transfer rate was then calculated from coolant mass flow, specific heat and measured temperature drop:

$$\dot{Q} = \dot{m} C_p (T_{ci} - T_{co}) \quad (3)$$

The effective mean thermal driving force across the radiator was represented by the logarithmic mean temperature difference:

$$LMTD = (\Delta T_1 - \Delta T_2) / \ln(\Delta T_1 / \Delta T_2) \quad (4)$$

where ΔT_1 and ΔT_2 are the terminal coolant-to-air temperature differences used for the radiator analysis. The overall heat-transfer coefficient was obtained from:

$$U = \dot{Q} / (A \times LMTD) \quad (5)$$

where A is the effective radiator heat-transfer area. Radiator effectiveness was expressed as the ratio of actual to maximum possible heat transfer at the same inlet conditions:

$$\varepsilon = \dot{Q}_{actual} / \dot{Q}_{max} \quad (6)$$

The thesis also used a temperature-based cooling-efficiency parameter:

$$\eta_c = [(T_{ci} - T_{co}) / (T_{ci} - T_a)] \times 100 \quad (7)$$

where T_a is ambient-air temperature. Representative measurement uncertainties were $\pm 0.5^\circ\text{C}$ for temperature, approximately $\pm 2\%$ for coolant flow and $\pm 1\%$ for engine speed. For two independent temperature measurements, the uncertainty in coolant temperature drop was estimated as:

$$w\Delta T = \sqrt{[(wT_{ci})^2 + (wT_{co})^2]} = \sqrt{(0.5^2 + 0.5^2)} \approx 0.71^\circ\text{C} \quad (8)$$

V. RESULT AND DISCUSSION

A. Coolant Temperature Behaviour

For both coolants, radiator inlet and outlet temperatures increased with engine speed, relatively consistent with the increase of thermal load and cooling-system activity. Water always kept a slightly lower temperature than the 50:50 EG-water in the water-side coolant temperatures. At 1500 rpm, the inlet and outlet temperatures of water were about 88.5°C and 81.8°C respectively; also at 2100 rpm were about 97.1°C and 87.4°C , while the EG-water mixture rose from around $90.2/82.8^\circ\text{C}$ (1500rpm) to $99.4/88.7^\circ\text{C}$ (2100rpm).

Table 2. Radiator coolant temperature and temperature-drop results

Engine speed	Water inlet	Water outlet	Water ΔT	EG-water inlet	EG-water outlet	EG-water ΔT
1500 rpm	88.5°C	81.8°C	6.7°C	90.2°C	82.8°C	7.4°C
1800 rpm	93.2°C	84.7°C	8.5°C	95.0°C	85.7°C	9.3°C
2100 rpm	97.1°C	87.4°C	9.7°C	99.4°C	88.7°C	10.7°C

At all three engine speeds, the drop in coolant temperature was greater with the glycol mixture. This should NOT be interpreted as larger net heat transfer. Due to a lower specific heat than water- However, it needs greater ΔT to move the same heat load. The temperature results therefore illustrate two complementary behaviours: water keeps the averaged coolant temperature lower, while the 50:50 mixture experiences a greater radiator temperature drop.

B. Heat-Transfer Rate, LMTD and Overall Heat-Transfer Coefficient

Both coolants saw a substantially increased heat-transfer rate at greater engine speeds. At 1500 rpm, approximately 17.2 kW was rejected by water compared to 16.8 kW for 50:50 EG-water. The values at 1800 rpm were about 25.3 and 24.8 kW, respectively, and they increased to approximately 32.1 and 31.5 kW in the second case at the speed of 2100 rpm. The margin stayed fairly moderate across the test range, but water proved to hold the thermal advantage at every operating point.

Table 3. Heat-transfer rate, LMTD and overall heat-transfer coefficient

Engine speed	Water $\dot{Q}$	EG-water $\dot{Q}$	Water LMTD	EG-water LMTD	Water U	EG-water U
1500 rpm	17.2 kW	16.8 kW	43.2°C	44.9°C	58 W/m ² ·K	54 W/m ² ·K
1800 rpm	25.3 kW	24.8 kW	45.1°C	46.9°C	81 W/m ² ·K	77 W/m ² ·K
2100 rpm	32.1 kW	31.5 kW	47.8°C	49.9°C	98 W/m ² ·K	91 W/m ² ·K

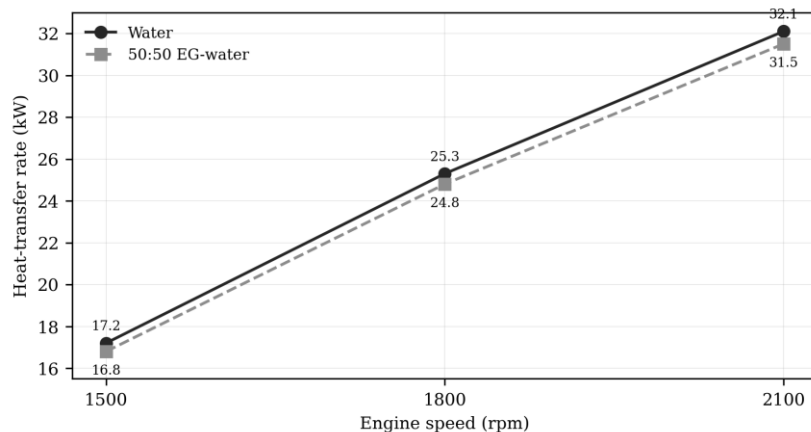


Fig. 3. Heat-transfer rate as a function of engine speed for water and 50:50 EG-water.

The higher LMTD values were ascribed to that the glycol mixture constantly experienced a warmer coolant temperature. At 2100 rpm, LMTD was around 49.9°C for EG-water and about 47.8°C for water respectively. However, despite the greater driving-temperature difference, water yielded a higher overall heat-transfer coefficient: 98 W/m²·K vs. 91 W/m²·K at 2100 rpm. This is in accordance with the observation of better thermal conductivity and lower viscosity in water. The heat transfer rate comparison thus ends with only a modest deviation instead of severe because

the glycol mixture has a much higher density (and secondly lower specific heat, but its influence is compensated by that) with bigger drop in temperature.

C. Radiator Effectiveness, Cooling Efficiency and Coolant Flow

Radiator effectiveness remained slightly higher with water throughout the test range. Water effectiveness was approximately 39.1%, 41.9% and 41.5% at 1500, 1800 and 2100 rpm, while the corresponding 50:50 EG-water values were 37.0%, 40.0% and 39.3%. Thus, the difference was close to two percentage points under the higher representative operating condition. The temperature-based cooling-efficiency metric showed the opposite ordering because it is based on coolant temperature drop relative to the inlet-to-ambient temperature difference and does not include coolant specific heat or mass flow.

Table 4. Radiator effectiveness, temperature-based cooling efficiency and coolant flow

Engine speed	Water eff.	EG-water eff.	Water η_c	EG-water η_c	Water flow	EG-water flow
1500 rpm	39.1%	37.0%	11.45%	12.29%	38 L/min	36.5 L/min
1800 rpm	41.9%	40.0%	13.45%	14.31%	44 L/min	43 L/min
2100 rpm	41.5%	39.3%	14.46%	15.42%	49 L/min	47.5 L/min

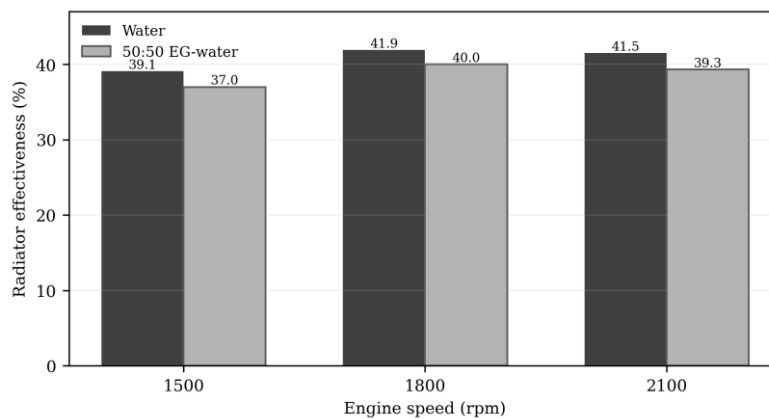


Fig. 4. Comparison of radiator effectiveness at the three engine-speed conditions.

Since the pump speed increased along with engine speed, coolant circulation would be higher at higher engine speeds. For instance, at 1500 rpm, water flow increased from around 38 L/min to 49 L/min at 2100 rpm; EG-water varied from about 36.5 to around 47.5 L/min. The flow of glycol mixture with slightly lower is consistent due to its dynamic viscosity being higher. The lower viscosity of water appears to limit hydraulic resistance but the glycol requires more pumping work under the same nominal circulation condition.

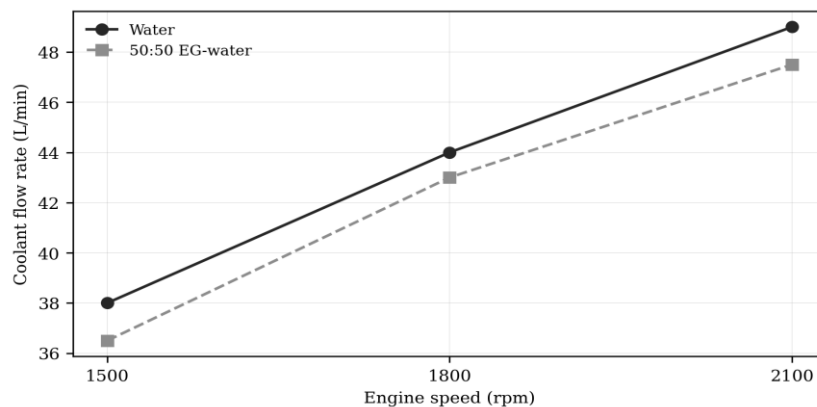


Fig. 5. Coolant flow rate as a function of engine speed for water and 50:50 EG-water.

D. Overall Comparative Performance

More importantly, in none of the tractor cooling systems tested was water the best coolant when water alone was compared based on thermal performance. It had slightly lower coolant temperatures, a higher heat-transfer rate, a greater overall heat-transfer coefficient at the pump exit, a better radiator effectiveness and circulated at a somewhat higher volumetric flow rate. The 50:50 EG-water mixture nevertheless exhibited an overall small thermal penalty. For example, at 2100 rpm the heat-rejection difference was about 0.6 kW and radiator effectiveness varied by about 2.2 percentage points. The larger coolant temperature drops with the glycol mixture, which is indicative of higher heat transport capability, is simply due to its lower specific heat.

Table 5. Overall comparison of water and 50:50 EG-water

Performance parameter	Water	50:50 EG-water	Preferred condition
Specific heat	Higher	Lower	Water
Thermal conductivity	Higher	Lower	Water
Viscosity	Lower	Higher	Water
Heat-transfer rate	Slightly higher	Slightly lower	Water
Overall heat-transfer coefficient	Higher	Lower	Water
Radiator effectiveness	Higher	Slightly lower	Water
Coolant temperature drop	Lower	Higher	EG-water
Pumping requirement	Lower	Higher	Water
Freezing protection	Poor	Excellent	EG-water
Boiling protection	Lower	Higher	EG-water
Practical engine protection	Limited	Better	EG-water

So the engineering equivalent is a thermal optimum vs an operational optimum. While water is the superior heat-transfer reference fluid for this, plain water isn't the most resilient long-term tractor coolant. You will trade some specific heat, conductivity and hydraulic ease but enjoy noticeably better low temperature protection, higher boiling margin as well as much better practical protection of the cooling system with the 50:50 EG-water mixture. Since its measured heat rejection is still near the water baseline, and given the conditions assessed, this makes the mixture a more balanced practical operating option.

VI. CONCLUSION

- 1) Water showed the strongest intrinsic thermal properties, with a representative specific heat of about 4.20 kJ/kg·K and thermal conductivity of about 0.67 W/m·K, compared with approximately 3.60 kJ/kg·K and 0.43 W/m·K for 50:50 EG-water. The glycol mixture was also more viscous, which slightly reduced coolant circulation.
- 2) Water maintained lower radiator inlet and outlet temperatures at corresponding engine speeds. The 50:50 mixture produced a larger radiator temperature drop, reaching about 10.7°C at 2100 rpm compared with 9.7°C for water, but the larger temperature drop did not indicate greater total heat transfer because the mixture had lower specific heat.
- 3) Heat rejection increased with engine speed for both coolants. At 2100 rpm, water rejected approximately 32.1 kW and 50:50 EG-water approximately 31.5 kW. The overall heat-transfer coefficient was also higher with water (about 98 W/m²·K versus 91 W/m²·K), confirming its superior coolant-side thermal performance.

- 4) Radiator effectiveness remained slightly higher with water, reaching about 41.5% at 2100 rpm compared with 39.3% for EG-water. Water also circulated slightly faster under the same engine-driven pump arrangement (49 versus 47.5 L/min at 2100 rpm), consistent with its lower viscosity.
- 5) For the tested conditions, water is the thermal optimum when maximum heat-transfer performance is the only criterion. The 50:50 ethylene glycol-water mixture is the better balanced practical coolant because its thermal penalty is small while it provides substantially improved freeze and boil protection and better suitability for long-term engine-cooling operation.

VII. FUTURE SCOPE

Further comparisons, including with EG concentrations 30:70, 40:60 and 60:40EG-water are needed to develop a continuous trade-off between enhanced heat-transfer ability, achievable viscosity and freeze/boil protection. They should also cover much higher engine loads, hot summer day operation and long-term field running while ploughing, rotavating, transporting and during PTO work. To improve the thermal-hydraulic assessment, direct measurements of radiator pressure drop, coolant-pump power and radiator air-flow rate should be considered. Tasteless Long-term coolant stability should also be evaluated, and material compatibility CORROSION should be examined, propylene-glycol or nanoparticle-enhanced alternatives could be compared with the conventional 50:50 EG-water baseline. An additional experimental study suggested that the numerical methodology could also be further used to analyse complex phenomena such as coolant velocity distribution and even radiator hot spots, introducing pressure loss, and treating non-uniform fan airflow (e.g. converting virtual flow rather than actual reference) which is not easy to measure experimentally.

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