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Fire risks of engine coolant leaks in buses

Coolant leaks have been highlighted as a potential cause of vehicle fires worldwide.[1,2,3,4] Several investigations by the Office of Transport Safety Investigations (OTSI) into bus fires in NSW have also identified leaking engine coolant as the likely first fuel for fire.[5,6,7,8,9] These findings have prompted discussions about the fire risks of coolant leaks. During research for this article, OTSI found there is misinformation regarding engine coolant fire safety in vehicle operational and non-operational (storage and handling) environments.

This inaugural OTSI Knowledge Article aims to provide a better understanding of the fire properties of engine coolants, the underlying science behind these properties, and the associated fire risks of coolant leaks relating to bus operations. The content is based on literature research and OTSI's investigation experience. It is intended for educational and awareness purposes and should not be considered a substitute for the manufacturer's advice regarding the use and storage of coolants.

Fire properties of engine coolants

Reports linking coolant leaks to vehicle fires raise the question of how flammable engine coolants are. This section addresses that question and provides information on the fire properties of coolants.

Engine coolants can and do catch fire. However, they do not catch fire readily and are not considered a fire risk at room temperature even when exposed to a spark or a flame for a short time.

For engine coolants to catch fire, they need to be heated to temperatures exceeding or exposed to a surface hotter than:

1) their fire point (i.e. > 120 °C)[10,11,12] if there is a spark or a flame present to ignite the vapours, or
2) their autoignition temperature (i.e. > 400 °C)[13,14,15] if there is no ignition source nearby.[*]

Even when the above conditions are met, there is generally a delay in ignition, that is, engine coolants need to stay in the above conditions for some time before catching fire. For a coolant to immediately (i.e. within 1 s) catch fire in the absence of a spark of a flame, it needs to be exposed to a surface hotter than its instantaneous ignition temperature (> 600 °C).[14]

Note that the temperature values listed above, including those listed in the safety data sheets of the coolants, are measured under controlled conditions using specific experimental setups. These values can vary significantly in real life scenarios. For example, autoignition temperatures of engine

[*] The safety data sheets of engine coolants list their flash points. Fire points are typically a few degrees higher than flash points. The definitions of these terms are given in the next section.

coolants have been reported to exceed 650 °C in some vehicle operating scenarios compared to about 400 °C in laboratory conditions.[12]

Additionally, factors such as age, condition, and composition of coolants can influence their fire properties. Used engine coolants, for example, have been reported to have lower flash points and autoignition temperatures likely due to lower water content compared to new coolants.[16]

The underlying science

The science of fire

Three elements are essential for a fire to occur: an oxidiser, a fuel source and sufficient thermal energy.[2] If the oxidiser is oxygen gas, it must be present at a minimum concentration of 10% in the atmosphere. The amount of fuel must also be within a specific range, known as the flammability range. Below this range, the fuel/air mixture is too lean to ignite and above this range, the mixture is too rich to ignite. These thresholds, called the lower flammability limit and the upper flammability limit, vary significantly depending on the fuel type. For example, petrol vapours cannot catch fire if their concentration surpasses 7.6%, while acetylene vapours can ignite up to a concentration of 81%. Finally, there must be enough thermal energy to heat the fuel/air mixture to its ignition temperature. This thermal energy can come from an ignition source, such as a spark or a flame, or by increasing the surrounding temperature.[17]

For ignition of liquids in an open environment, the vapour above the liquid acts as the fuel, and air as the oxidiser. The minimum temperature at which a liquid produces enough vapour to reach the lower flammability limit (i.e. to form an ignitable mixture with air) is called the flash point. When a liquid is heated to its flash point, an ignition source with sufficient thermal energy will cause a fire, however, this fire will only be momentary and will self-extinguish once the vapor cloud burns. For sustained burning, the liquid must be heated to or above its so-called fire point which is typically a few degrees higher than its flash point, and the vapours then ignited through an ignition source. If there is no ignition source present, the vapours must be heated to their so-called autoignition temperatures (by means of increased surrounding temperature).[17]

Decoding engine coolants

Engine coolants are largely a mixture of antifreeze (generally 30 to 60%) and water. This solution is supplemented with small quantities of corrosion inhibitors, pH buffers, bittering agents, and dyes for a variety of practical reasons. Of the two major components of coolants, water is, of course, incombustible, thus leaving antifreeze as the main ignitable component. The two common antifreeze types used in engine coolants, ethylene glycol and propylene glycol, have similar thermophysical and fire properties.[13,18,19] Therefore, the discussion here focuses on the values reported for ethylene glycol only.

Pure undiluted ethylene glycol (or ethanediol) has a flammability range between 3.2% and 15.3% (in air), a flash point of 111-121 °C and an autoignition temperature of 398-434 °C.[13,14,18] Since water is incombustible, its addition to ethylene glycol makes it more difficult for the resulting mixture to catch fire. Technically, this difficulty translates to higher flash and fire points of ethylene glycol/water mixtures compared to undiluted ethylene glycol. As an example, a 60/40 ethylene glycol/water solution (a common composition for an engine coolant) has a flash point of 141–143 °C compared to 111-121 °C for undiluted ethylene glycol.[12] Studies have also shown that the higher the water content the higher the ignition temperatures of the resulting mixtures.[12,20]

Addition of water to ethylene glycol also brings other challenges. The boiling point of water (100 °C) is lower than the flash (111-121 °C) and boiling (about 197 °C) points of ethylene glycol.[18] Therefore, once the coolant is heated past 100 °C[†], the water in the coolant starts boiling off. The vapour from boiling water makes the fuel/air mixture above the coolant too lean to ignite. However, as the water continues to boil, its concentration in the coolant starts reducing. When the water content is low enough that the vapour/air mixture above the coolant reaches the lower flammability limit, the coolant is perceived to have reached its flash point.

Fire risks of coolant leaks in buses

The hottest locations on a vehicle under normal operating conditions are the exhaust manifold, turbocharger and exhaust pipe. In heavy vehicles (including buses), these components can exceed the autoignition temperatures of engine coolants.[2] Consequently, if the leaked coolant comes in contact with these areas, autoignition becomes a potential risk. Alternatively, if the coolant leaks onto the surfaces of the engine that are hotter than the fire points of the coolant, but lower than their autoignition temperatures, then ignition from a stray spark from a high voltage wire or an electrical component becomes a potential risk.

However, as discussed before, the ignition temperatures of engine coolants can be significantly different in vehicle operating scenarios compared to the values listed in the safety data sheets. Some contributing factors behind these variations include the amount of coolant leak, pattern of spray, coolant's condition and water content, proximity of coolant leaks to hot engine surfaces (e.g. exhaust manifold or turbocharger), the amount of time coolant was exposed to the hot surface, the amount of ventilation and the presence or absence of an ignition source. Further, the surface temperatures of the hottest units of the buses can also vary depending on the presence or absence of insulation coverings, condition of these coverings, and if the vehicle is operating under normal or at-fault conditions.

With so many variables, determining the ignition temperature and mechanism of the engine coolant in specific incidents is challenging. This is why post-incident investigations often rely on the heat patterns, fluid residues, condition of hoses and the method of elimination (i.e. lack of evidence towards any other fuel source) to conclude a coolant-initiated fire.

High variability in multiple contributing factors perhaps also explains the conflicting reports in literature on the fire risks of engine coolants in vehicle operating scenarios. For example, where one study states that ethylene glycol coolants are highly unlikely to be the first fuel in a vehicle fire,[12] another claims coolant fires to probably be "the most common among older automobile engine fires".[4] As per the first report, the autoignition of ethylene glycol in vehicle operating scenarios is only possible "under very specific and unlikely conditions". Whereas the second study claims that autoignition of glycol has been achieved, reproduced and documented many times and the results have been used in courtrooms to prove "beyond a doubt" the manner in which coolant fires occur in vehicles in real life scenarios.

Conclusion

Considering the fire properties of coolants, typical surface temperatures of engine components in buses, literature studies on coolant's combustibility in real vehicle operating scenarios, numerous reports on coolant-initiated vehicle fires worldwide and OTSI's own experience in investigating bus fires, we have concluded that coolant leaks in buses do pose a fire risk. This risk is highly variable and a nuanced and context-specific approach is required for its assessment. However, the risk

[†] In actuality, the initial boiling point of an engine coolant is about 108 °C. Mixing antifreeze with water slightly increases its boiling point.

increases if the coolant leaks onto the high-temperature components of the engine including exhaust manifold or turbocharger, or if there is an ignition source present in the vicinity of the leak.

To reduce the risk of fire, bus operators should always prepare and use engine coolants in accordance with the original equipment manufacturer's instructions. They should also follow good maintenance practices to prevent coolant leaks. This includes regular inspection and maintenance of coolant hoses, their insulation coverings and their connections.

Some common myths

Engine coolants are highly flammable

Truth: Although engine coolants can and do catch fire, for storage, handling and transport purposes, they are classified as combustible liquids instead of flammable[‡]. That is, they do not catch fire readily and are not considered a fire risk at room temperature. Engine coolants are safe to use under normal vehicle operating scenarios, provided they are used as per the manufacturer's guidelines and there are no coolant leaks.

Engine coolants will catch fire if heated to their fire points

Truth: This is only true if there is an ignition source, such as a flame or a spark present in the vicinity of the coolant vapours. In the absence of an ignition source, coolants will not catch fire until they are heated past their autoignition temperature, which is about three times higher than their fire points.

Coolant leaks are harmless and pose no fire threat

Truth: Coolant leaks do pose a fire risk. There are several reports of coolant-initiated vehicle fires worldwide, including multiple bus fires in NSW. The fire risk from coolant leaks does, however, vary from negligible to significant, depending on factors such as the location and amount of leak (which can be difficult to detect as insulation coverings can hide splits and deterioration), pattern of spray, coolant's condition and water content, proximity of coolant leaks to hot engine surfaces (e.g. exhaust manifold or turbocharger), the amount of time coolant was exposed to the hot surface, the amount of ventilation and the presence or absence of an ignition source.

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[‡] As per the Australian Dangerous Good Code and Australian Standard AS1940:2017, a liquid is classified as "flammable" if its closed-cup flash point is less than or equal to 60 °C. Liquids with a flash point greater than 60 °C are classified as combustible liquids. Here "closed cup" refers to the type of experimental apparatus used to determine the flash point and is detailed in Australian Standard AS2106.

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