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Under Hood Temperature Measurements

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ABSTRACT

In addition to gasoline, other automotive fluids such as engine oil, transmission oil, brake fluid, coolant and power steering fluid are combustible and if exposed to an ignition source can ignite and result in a vehicle fire. Ignition sources may include sparks, flames, or hot engine or exhaust components.

Under normal vehicle operating conditions these fluids are well contained and do not pose a fire threat. However, the risk of fire increases if the fluids are spilled or released in a collision.

In-vehicle temperature measurements were conducted to identify operating engine and exhaust temperatures under various driving conditions ranging in speed from 48 to 112 km/h (30 to 70 mph).

INTRODUCTION

In the presence of an ignition source, spilled automotive fluids such as engine oil, transmission oil, brake fluid, coolant and power steering fluid can pose a fire threat. Additionally, the potential threat of a fire increases with the greater volume of gasoline that may be released as a result of a collision. If exposed to an ignition source, any of these fluids can ignite and result in a vehicle fire. Ignition sources may include sparks, flames, or hot engine or exhaust components.

Under normal vehicle operating conditions automotive fluids do not pose a fire threat as they are well contained in reservoirs and hoses. However, following a collision the risk of fire can increase if under hood fluids are spilled or expelled and come into contact with a suitable ignition source such as sparks or hot surfaces. The research presented sought to identify a representative range of surface temperatures that may be attained while driving.

The risk of hot surface ignition of spilled fluids would depend on whether contact with a sufficiently hot surface is made and whether the conditions are prevalent for hot surface ignition to occur. As indicated by Colwell and Reza [Ref. 1]:

> "Unlike the flash point and the minimum auto ignition temperature, which are well defined combustion properties that can be measured with accepted ASTM standards, the temperature at which hot surface ignition occurs is not a fundamental fluid property and is strongly coupled to numerous factors, including the properties of the surface, the liquid spray or stream and the local airflow. Because of this coupling, the temperature required for ignition can vary widely."

With this in mind, published experimental results for hot surface ignition temperatures of several automotive fluids are presented in Table 1 for reference purposes. These results were obtained from various sources under various test conditions [Ref. 1, 3, 4, 5 and 6]. The variations in test methodology and the probabilistic nature of hot surface ignition result in the wide range of ignition temperatures presented.

Table 1: Reported hot surface ignition temperatures of some engine compartment fluids.

Fluid Type	Hot Surface Ignition Temperature ^{A} (ºC)	Ref.
New Motor Oil	510 – 610 320 - 335	[Ref. 1] [Ref. 3]
Used Motor Oil	315 - 335	[Ref. 3]
New Synthetic Motor Oil	320 - 370	[Ref. 3]
Used Synthetic Motor Oil	335 - 365	[Ref. 3]
Brake Fluid	545 – 575 280 - 340 371	[Ref. 1] [Ref. 3] [Ref. 4]
Power Steering Fluid	535 – 620 325 - 345 454	[Ref. 1] [Ref. 3] [Ref. 4]
Automatic Transmission Fluid	500 – 600 315 - 320 482	[Ref. 1] [Ref. 3] [Ref. 4]
Antifreeze and Engine Coolant	550 – 600 550 - 675 510	[Ref. 1] [Ref. 3] [Ref. 4]
Gasoline	610 – 670 (note B) 718 – 826 667-735	[Ref. 1] [Ref. 4] [Ref. 5] [Ref. 6]

Notes: A) Reported hot surface ignition temperatures for the specific conditions of the test methodology used.

B) Arndt was unable to establish hot surface ignition with surface temperatures ranging from 427 °C to 649 °C.

BACKGROUND

Tests have been conducted on four vehicles under various driving conditions in an attempt to measure under hood engine and exhaust temperatures [Ref 7]. The tests comprised level road and uphill driving at constant speeds until the recorded engine and exhaust component temperatures appeared to stabilize. The vehicles were stopped at the side of the road and the engine was turned off. This procedure simulates a vehicle crash where the vehicle comes to a sudden halt with the engine shutting off. Once the vehicle was stopped, the temperature measurements continued for a period of 20 minutes.

A stretch of highway approximately 1.6 km (1 mile) in length with a 7% grade was selected for the uphill driving tests. The length of the hill was insufficient to allow the vehicle temperatures to stabilize, consequently, the hill was ascended and descended three times. On the third ascension the vehicle was pulled off to the side of the road and the engine was turned off. The repeated process of ascending and descending the hill stabilized the peak temperatures achieved at the crest of the hill prior to the engine being turned off. Similarly to the level road testing, the temperature measurements were continued for a period of 20 minutes or until the maximum temperature dropped below 200 ºC. It should be noted that the peak temperatures attained may be higher on longer continuous hills.

Insulated K-type thermocouples, recommended by Omega® (model XCIB type 4), were used to measure vehicle surface temperatures at eleven locations under the hood and along the exhaust system. The use of insulated thermocouples was further suggested to avoid electrical noise on the signals. The recommended thermocouples, which were amenable to being clamped to the surface to be measured, were firmly secured to each location with stainless steel hose clamps in a manner consistent with the manufacturer's suggested method of attachment. The thermocouples were aligned so as to ensure maximum surface contact with the mating surface. Omega® four channel and eight channel data loggers recorded the temperatures at five second intervals.

RESULTS AND DISCUSSION

The peak surface temperatures recorded ranged from 374 °C to 550 °C and depending on the vehicle, they were recorded on the exhaust manifold or on the catalytic converter. However, the peak temperatures occurred following an anomaly in the temperature time histories in which the exhaust components appeared to increase in temperature after the vehicles were pulled to the side of the road and their engines stopped. An example of the temperature increase is shown in Figure 1. It should be noted that such an increase may be expected on the catalytic converter where continued chemical activity can contribute to an increase in surface temperature.

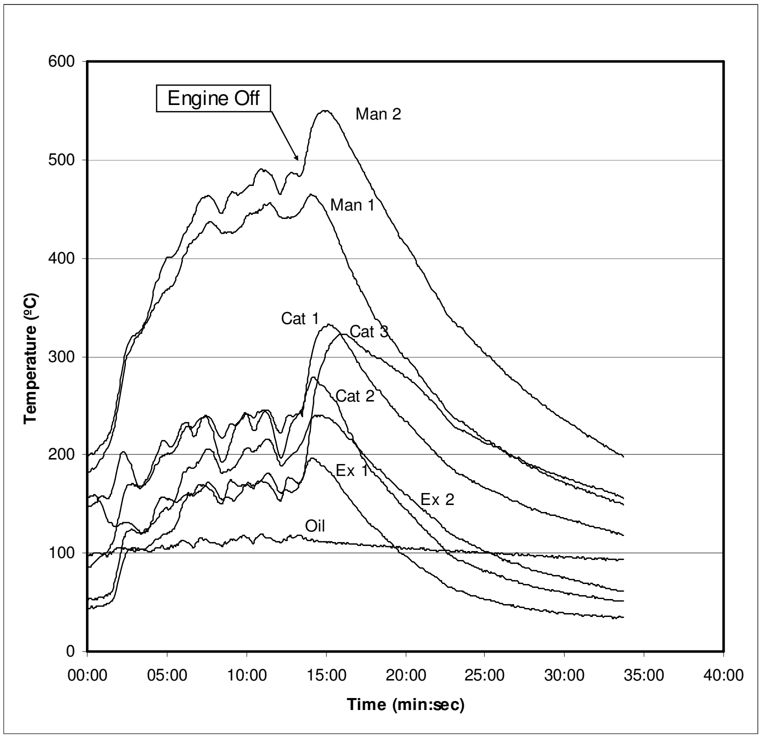

Figure 1: Surface temperature profile of a hill test at 112 km/h.

The removal of forced convective cooling, when the vehicles were stopped, was offered as an initial explanation for the phenomenon observed. However, upon further consideration the clamps and the thermocouple housing were believed to be acting as cooling fins, thereby reducing the observed temperature at the thermocouple bead location while the vehicles were in motion. When the vehicles were stopped the added cooling effect from the clamp was reduced and the temperature increased to be closer to the surrounding exhaust component surface temperature.

Discussions with expert vehicle fire investigators suggested that the increase in temperature was a physical phenomenon that may occur when an engine is turned off. A reference to this phenomenon was even found in the National Fire Protection Association's guide for fire investigation [Ref. 2]. It was also suggested that thermocouple attachment method may also have been responsible for temperature increase.

Complete results for the eleven measurement locations [Ref. 7] are not presented due to the anomaly and the associated uncertainty in the measured temperature values. In an effort to investigate the anomaly and the possible role of the thermocouple, an additional test on one vehicle was undertaken to evaluate thermocouple types and attachment methods. The results of the testing are discussed herein.

ADDITIONAL IN-VEHICLE TEMPERATURE MEASUREMENTS

An additional set of in-vehicle temperature measurements was conducted to assess thermocouple types and attachment methods on recorded component temperatures. The same procedures as described for the initial vehicle measurements were followed. Measurements, however, were only recorded at two locations along the exhaust system.

Five K type thermocouples were used to measure the temperatures at each of two locations along the exhaust system of a 1996 Ford F150 V8 pickup truck. The first location was at the union of the driver side exhaust manifold with the catalytic converter pipe section. The catalytic pipe was comprised of two catalytic converter modules joined by a short section of pipe. This short pipe was selected as the second location for measuring surface temperatures. In both locations the thermocouples were placed on the surface of the pipe along the circumference defined by a cross sectional plane perpendicular to the axis of the pipe. The thermocouples were installed on a new section of exhaust pipe prior to being installed in the vehicle. The thermocouples and their attachment method are listed in Table 2 and their placement is shown in Figure 2.

Table 2: Thermocouple types and attachment methods.

Thermocouple Type	Thermocouple Make/Model	Attachment Method
Surface Temperature (same as recommended for initial testing)	Omega Hi Temperature XCIB Style 4	Clamped
Thin Film Surface Temperature	Omega Cement-on Style 2, CO2-K	Cemented
Bead	Omega Ready Made 5SRTC-GG-K	Brazed
Bead		Cemented
Surface Temperature Probe	Omega Weld Pad Probe PDR	Welded

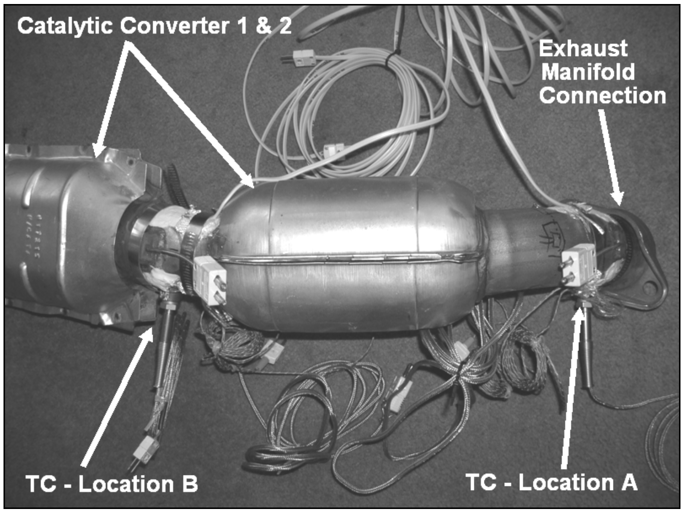

Figure 2: Thermocouple placement on exhaust pipe.

The temperatures at the two locations on the exhaust system were measured under two loading conditions that were achieved by level road driving and uphill driving. The driving tests were only conducted at 60 mph (96 km/h).

The temperature-time histories of the thermocouple measurements for the level road and uphill driving tests are shown in Figure 3 to Figure 6.

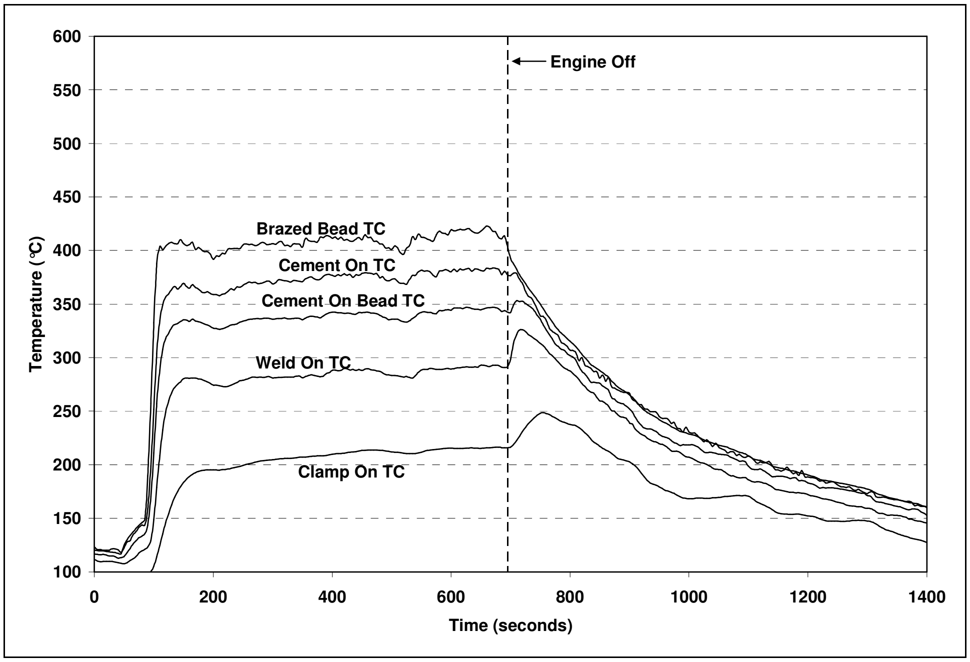

Figure 3: Level road – temperature time history at location A.

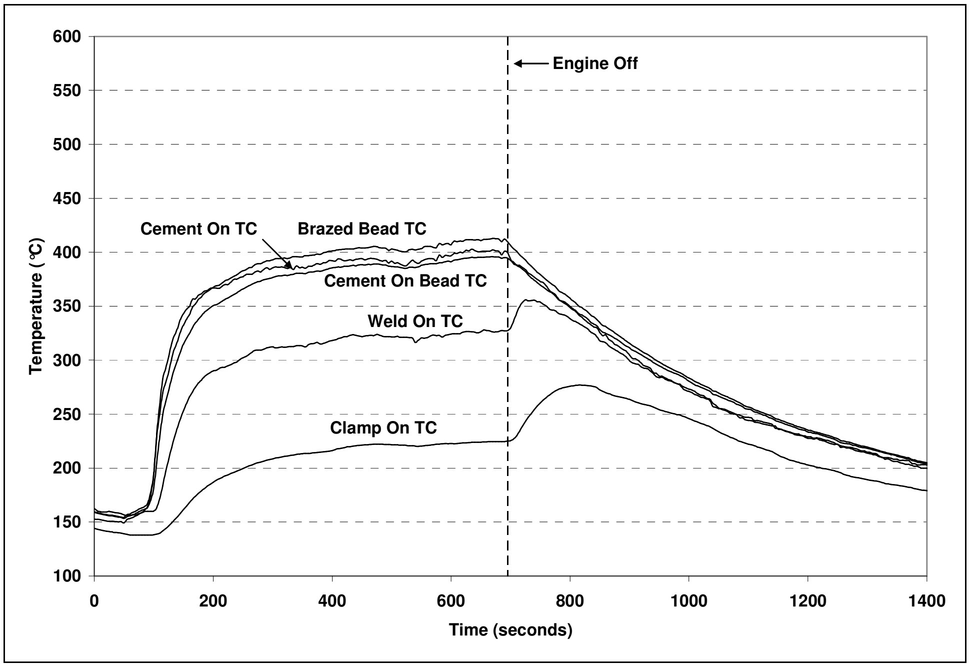

Figure 4: Level road – temperature time history at location B.

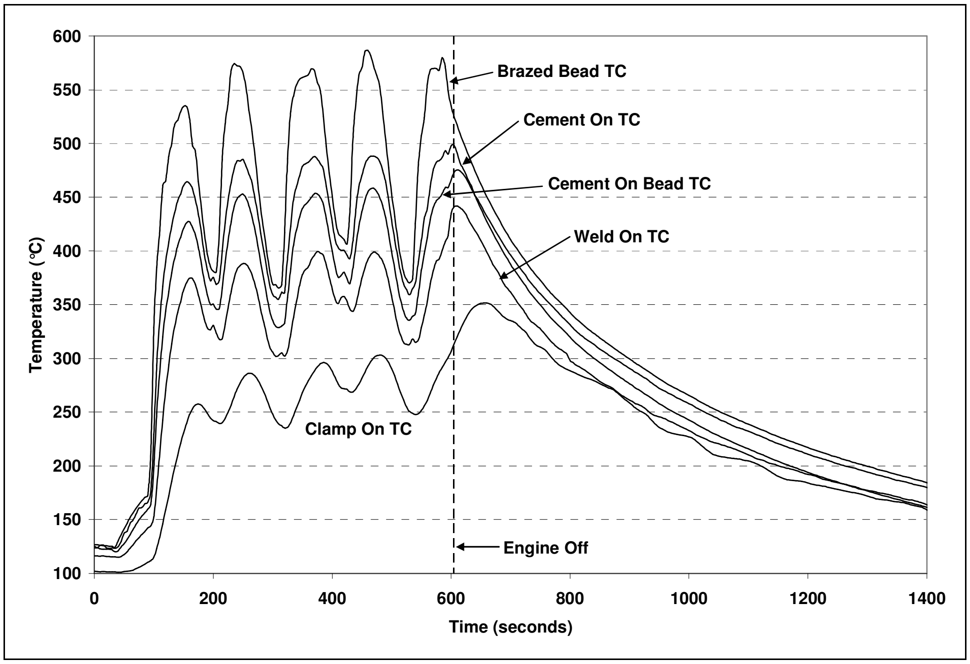

Figure 5: Uphill- temperature time history at location A.

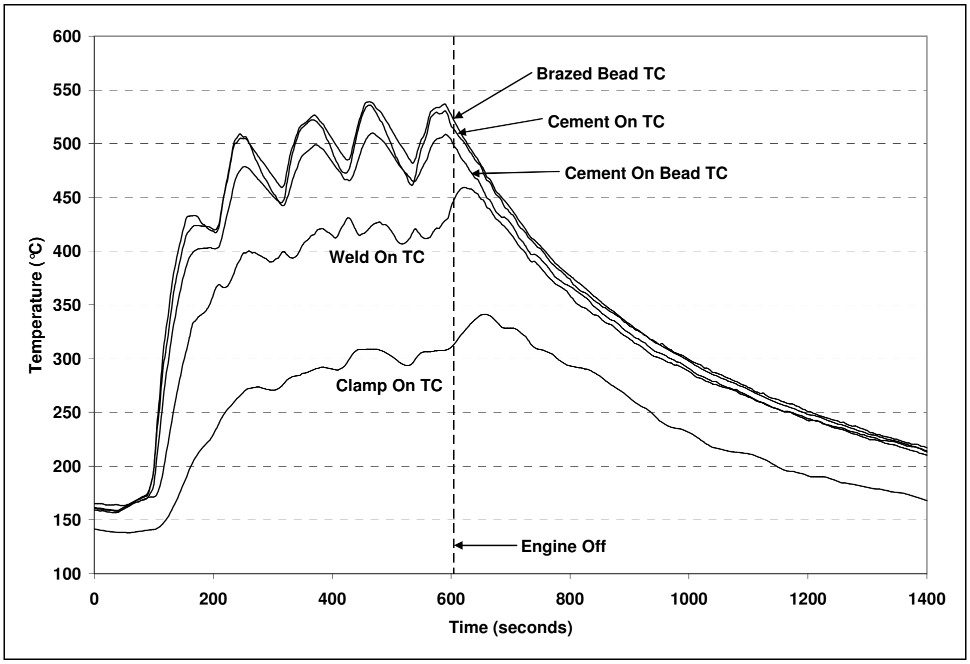

Figure 6: Uphill- temperature time history at location B.

The undulations in the temperature measurements seen in the uphill driving temperature time histories (Figure 5 and Figure 6) are directly linked to ascending or descending of the hill as previously described in the test procedure.

The brazed-on thermocouple bead registered the highest surface temperature measurements at both measurement locations and under both driving conditions. The clamp-on surface temperature thermocouple measured the lowest. However, the temperatures recorded by the brazed-on, the cemented-thin-film and the cemented-bead thermocouples at location B were within approximately 30 °C compared to a range of almost 100 °C at location A. A possible explanation for the difference in the temperature ranges measured at the two locations may be due to the turbulence of the exhaust gas flow within the pipe. At location A the exhaust gases in the four manifold pipes have traveled different distances from the exhaust valves, thereby producing an uneven temperature distribution. Additionally, the exhaust manifold clamp introduced an uneven thermal mass distribution (see Figure 2) at location A which was less exposed to airflow than location B. At location B, the exhaust gas temperature has stabilized after having passed through the first catalytic converter. The smaller differences observed in this location could be due to the differences in convective cooling occurring around the circumference of the pipe at the measurement location.

The clamped-on surface temperature thermocouple and the welded-on surface temperature probe had noticeably slower response times than the other thermocouples used. This is likely due to the thermal mass associated with these thermocouples' exterior sheathing which may have acted like heat sinks delaying the discernment of temperature changes. Diminished thermal conductivity between the pipe surface and the clamped thermocouple would have also contributed to the slower response time of the clamped-on thermocouple. This, in conjunction with the additional forced convective cooling that may be associated with the thermocouples sheathing or clamp may be responsible for the 75 °C to 175 °C lower temperatures measured when compared to the brazed-on-bead thermocouple.

Temperature increases that occurred after the engine was turned off were observed with the clamped-on thermocouple, the welded surface temperature probe and the cemented thermocouple bead. These increases are summarized in Table 3 for the different driving conditions and measurement locations.

Table 3: Summary of observed temperature increases after the vehicle engine was turned off.

Test Condition	TC Type	Temperature at Engine Shut-off (°C)	Peak Temp (°C)	Temperature Increase (°C)	Time of Peak After Engine Turned Off (s)
Level Road TC location A	Clamped	215	249	34	60
	Cemented Thin Film	377	377	0	0
	Brazed	403	403	0	0
	Cemented Bead	342	353	11	15
	Welded Probe	292	326	34	25
Level Road TC location B	Clamped	225	277	52	120
	Cemented Thin Film	399	399	0	0
	Brazed	410	410	0	0
	Cemented Bead	394	394	0	0
	Welded Probe	327	356	29	30
Uphill TC location A	Clamped	313	352	39	50
	Cemented Thin Film	499	499	0	0
	Brazed	526	526	0	0
	Cemented Bead	473	475	2	5
	Welded Probe	441	442	1	5
Uphill TC location B	Clamped	313	341	28	50
	Cemented Thin Film	514	514	0	0
	Brazed	522	522	0	0
	Cemented Bead	498	498	0	0
	Welded Probe	447	459	12	15

The cemented bead thermocouple at location A exhibited a comparatively small temperature increase in two instances. As indicated previously, there appeared to be a temperature gradient around the circumference of the pipe at this location. When the engine was turned off the immediate response would have been for the local low temperature location to equalize with an adjacent higher temperature. This may have resulted in a brief temperature increase. At location B, where the temperature gradient was not as apparent, such a temperature equalization effect would not have been as apparent. Regardless, if the hottest location is selected an increase in temperature would not be expected.

The additional forced convective cooling associated with the clamped-on and the welded probe thermocouple sheathing likely contributed to the lower temperature measurements. With the vehicle stopped and the engine turned off the forced convective cooling would cease, allowing the measured temperature to increase and approach the bead and thin-film thermocouple measurements. The higher temperatures, however, were never actually reached by the clamped-on or welded probe thermocouples. Therefore, both these thermocouples are conservative in their measurement of the exhaust surface temperatures and indicate that the measurements on the initial four vehicles under represent the peak temperatures that were attained.

After the peak temperatures were reached the thermocouples all cooled at approximately the same rate.

SUMMARY

Following a collision, hot surfaces may be potential ignition sources for spilled engine compartment fluids such as engine oil, transmission oil, brake fluid, coolant, power steering and gasoline. In previous research, exhaust system temperatures of four vehicles were measured at eleven locations under several driving conditions [Ref. 7].

The recorded surface temperatures were measured while driving and were continued after the vehicles were pulled off to the side of the road and the engine turned off. This simulated a collision in which the vehicle may have come to a sudden halt.

Under both the level road and the uphill driving conditions a phenomenon was observed in which the measured temperatures initially increased after the engines were turned off.

To investigate the observed increases in temperature measurements after the engines were turned off, additional tests were conducted on a single vehicle to determine the effect of 5 different thermocouple types and attachment methods. Brazed-on, welded-on, clamped-on and cemented-on thermocouple attachment methods were employed to measured surface temperatures at two locations on the exhaust system during level road and uphill driving at 60 mph (96 km/h). At both measurement locations and under both driving conditions the brazed-on thermocouple bead registered the highest temperatures whereas the clamp-on thermocouple, similar to that used in the initial testing registered the lowest temperatures.

The two thermocouples with higher thermal mass associated with their construction, namely the clamp-on and the welded-on probe thermocouple registered lower temperatures, due to the forced convective cooling acting on the thermocouple sheathing. These two thermocouples also exhibited a delay in response and exhibited a significant temperature increase after the vehicle engine was turned off. The delay in response was associated with the thermal mass of the thermocouple construction, whereas, the measured increase in surface temperature was believed to be associated with the cessation of forced convective cooling acting on the thermocouples' housing and where applicable on the clamp attachment method. Consequently, these types of thermocouple are not appropriate for surface temperature measurements where forced convection or quickly changing temperatures may be experienced. Furthermore, this suggests that the surface temperature measurements of the initial four vehicles are lower than the actual temperatures that were attained and that the increase in measured temperature after the engine was turned off was a phenomenon associated with the specific thermocouple and attachment method.

For the most part, the results of the thermocouple evaluations suggest that the temperature increases previously recorded [Ref. 7] were an artifact of the thermocouple and attachment method. Nevertheless, there was some indication that a slight temperature increase may be possible in areas where localized thermal gradients exist. When the source of heat is removed the region of lower temperature would increase to equalize with a decreasing higher temperature region. If the hottest location is selected, one would not expect to see an increase in temperature.

In consideration of possible thermal gradients around the circumference of the pipe at the measurement locations, the brazed-thermocouple bead and the cemented-on thin film thermocouple produced similar results. However, the thin film thermocouple required more effort and preparation to install. Generally, the brazed-on thermocouple bead would be recommended for further measurements under similar conditions to those discussed.

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