

IGNITION MISFIRE MB CIS-e Engines

Author: Robert MacDonald
Email: robm.UKGB@gmail.com

Mercedes-Benz M119, M104 and M103 Continuous Injection System (CIS-e) engines with electronic ignition from the early 1990's were known for difficult-to-diagnose problems with engine hesitation and misfiring.

Typical symptoms include intermittent misfiring and hesitation when idling, accelerating, and cruising. The vehicle might run fine initially, but after it is switched off for 15 minutes or so and restarted, it can misfire badly or worse, cut out.

One of the main causes of this type of misfiring is moisture in the distributors, which condenses on the inner surface of the cap(s), causing arcing between the high tension poles, leaving the tell-tale carbon tracking on the inside of the cap(s). Typical remedies involve either regular cleaning or costly replacement of the distributor caps.

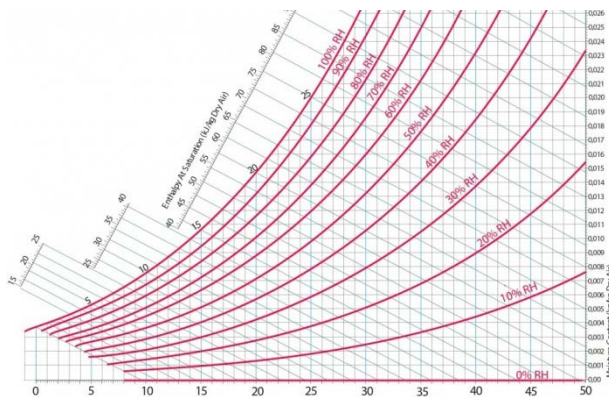


This article describes my DIY research and testing to try to establish, once and for all, the factors behind the misfire problem on my 1992 500SL. Various solutions are examined, aimed at promoting ventilation, dispersal and also exclusion of the water vapour inside the distributor caps.

AIMS

The purpose of this article is to ascertain the root causes of the misfiring in the CIS electronic ignition engine by measuring the physical properties of the air-vapour mixtures inside a running distributor, and through the use of psychrometric graphs and standard physics equations of enthalpy, analyse and manipulate the data collected to determine the most practicable solution to either minimise the risk of misfiring or find a permanent cure.

The normal diagnostics necessary to confirm an ignition misfire on a CIS-e engine have already been extensively covered in other publications and this is not the focus of this article. It is assumed that the misfire condition has already been confirmed by inspecting the output voltages to each sparkplug using a scope, and the carbon tracking in the distributor cap has been established by visual inspection.



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TEST METHODOLOGY

An 8mm diameter hole was drilled through the top of the distributor cap midway between two of the high tension poles and a small hygrometer and temperature remote sensor was glued in place to enable direct readings to be measured of the relative humidity (RH%) of the air inside the distributor and the temperature of the cap against time while the engine was idling and warming up.



Figure 2 Hygrometer/Thermometer

Using a FLIR infrared thermal imaging gun, the temperature of the surface of the alloy head adjacent to the recess in the head for the distributor was also recorded against time.



Figure 1 Hygrometer/Thermometer

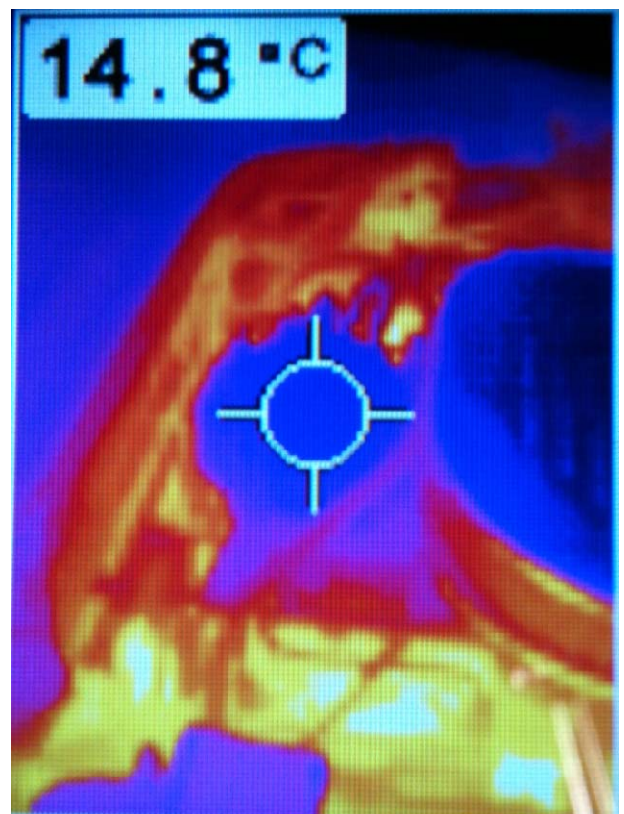


Figure 3 FLIR TG 165 IR Thermal Gun

At the beginning of each test the ambient relative humidity, temperature and barometric air pressure were recorded.

Figure 4 Live Recording

Firstly a control test was undertaken in August 2017 under warm summertime conditions that were commensurate with normal running without misfire. The physical and thermodynamic properties of the gas-vapour mixtures inside the running distributor data were collected and analysed. Misfires were recorded by measuring the HT voltage from the coil using a UEI ADL 7100 lab scope. The tests were repeated in early February 2018 under cooler, wetter wintertime conditions where abnormal running and misfires were anticipated.

**Figure 5 Hygrometer/Temperature Probe**

The August 2017 'control' run with the OE setup was undertaken to investigate: -

1) the warm up and cooling phases of the distributor in summer conditions, where we would not expect any misfires;

The additional runs in February 2018 started with the OE setup (without modification) to investigate: -

2) the warm up and cooling phases in winter conditions, where we would expect misfiring;

3) the warm up and cooling phases inside the cap taking into account the moisture build up from run #2;

4) the effects of a short run; turning the engine off for a brief period; and restarting again. Anecdotally we know that this produces the worst conditions for misfire;

5) the longer term changes inside the distributor while the engine is idling for 90 minutes;

This completes the first stage of the investigation of the unmodified OEM distributor.

Simple modifications were then made to the distributor to increase the ventilation and dispersion of internal gases in the distributor, and the engine was tested as follows: -

6) **Modification Type #1** - a single row of additional slot vents near the top of the cap, cut in a similar manner to the existing around the base of the cap.

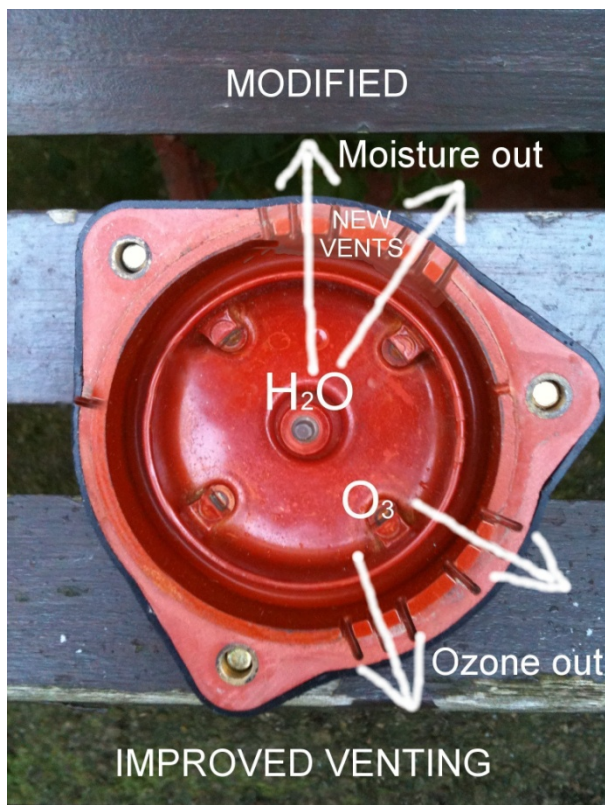


Figure 6 OEM Cap - Trapped Moisture

7) **Modification Type #2** - two rows of additional vents near the top of the cap, cut in a similar manner to the existing.

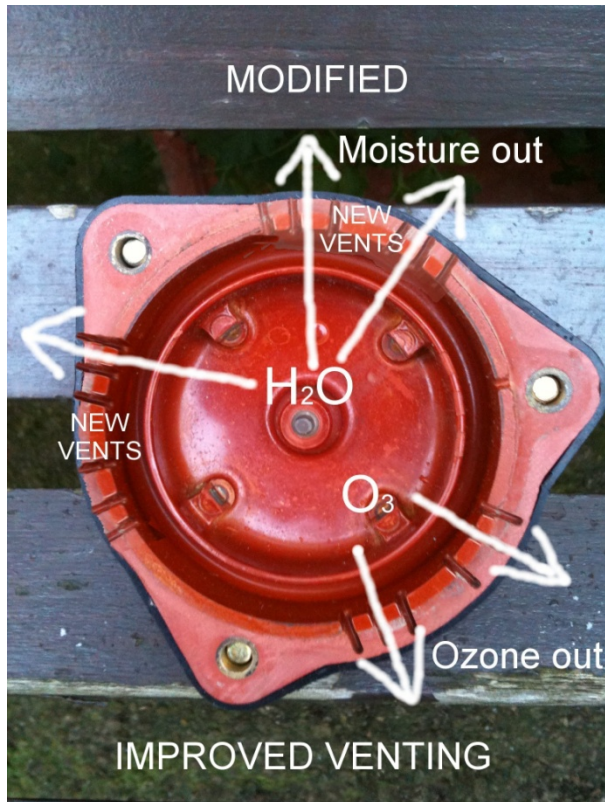


Figure 7 Modified Cap - Improved Venting

APPARATUS

The equipment used in these tests generally falls into the category of un-calibrated DIY electronics and a professional UEI ADL 7100 Dual Trace Automotive Lab Scope (Snap on/Sun Equivalent LS2000) to monitor misfires, stopwatch, and a FLIR TG 165 Infra-red thermal imaging camera with digital readout (used to record surface temperatures).

The hygrometer/temperature probe was an unbranded device of low \$\$ value, although it was purported by the vendor to be accurate, I was able to confirm its accuracy to $\pm 1^{\circ}\text{C}$ against a reliable thermometer, and $\pm 5\%$ RH against local weather station data.

In terms of reliability, we are interested in the RH trend and not necessarily the absolute accuracy of discrete RH values, and therefore the chosen hygrometer was considered to be fit for the purposes of this study.

Local Weather Station Data:

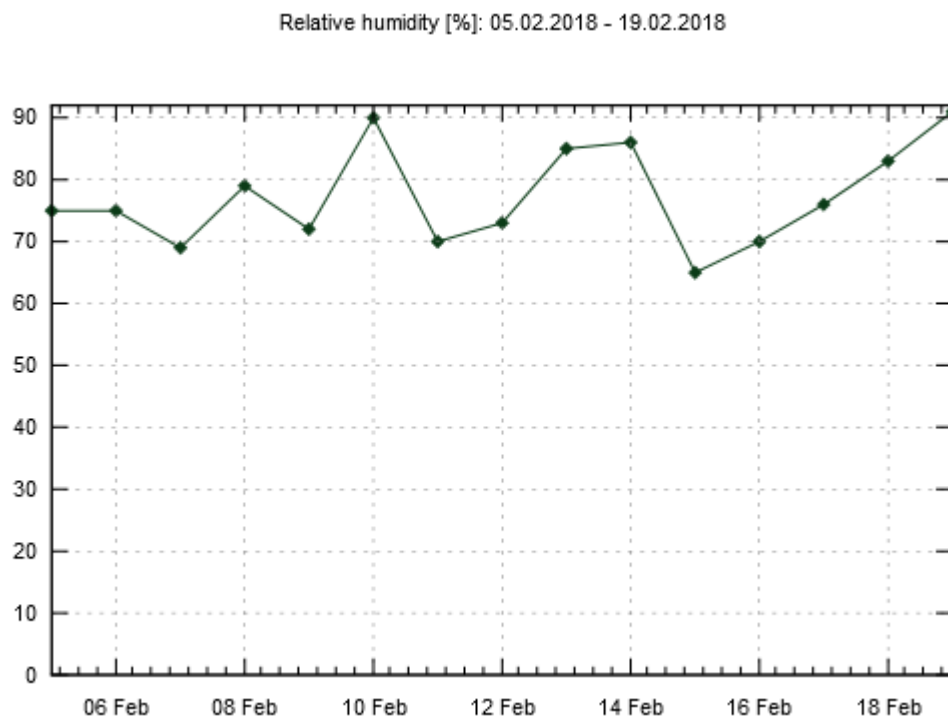


Figure 8 Local Weather Station Data (2 miles)

Technical Specifications of Apparatus

UEI ADL 7100 Dual Trace Automotive Lab Scope (Snap on/Sun Equivalent LS2000).

Operation temperature: 32 °F to 104 °F (0 °C to 40 °C)

Relative Humidity: 0 % to 80 % at 32 °F to 95 °F (0 °C to 35 °C)

Max Voltage: 300 V

DC Accuracy : 0.3 %

Bandwidth: DC to 5 MHz (-3dB)

Sample rate : 25 Mega samples/second



Figure 9 Lab Scope



FLIR TG 165 Infra-red thermal imaging camera with digital readout.

Basic accuracy: $\pm 1.5\%$ or $\pm 1.5^{\circ}\text{C}$

Temperature measurement range: -25 to 380°C (14 to 716°F)

Built-in 2.0" TFT screen

Distance-to-spot-ratio: 24:1

Measurement resolution: 0.1°C/°F

Response time: 150 milliseconds

Imaging detector: FLIR Lepton

Microbolometer Focal Plane Array (FPA)

Image resolution: 4800 pixels (80 x 60)

Figure 10 FLIR TG 165 IR Thermal Imaging Gun

Digital LCD Thermometer Hygrometer Temperature Humidity Indoor Meter Probe.

Specifications:

Digital Thermometer

Sampling Period: 10S

Temperature Range: -40°C ~ 70°C

Temperature Accuracy: 1°C

Operating Voltage: 2pcs 1.5v LR44 batteries(Include)

Dimension: 48 x 28.5 x 15.2mm

LCD Dimension: Approx. 40 x 22.5mm



Figure 11 Hygrometer/Temperature Probe

Secondary ignition
capacitive pickup
probe



Figure 12 Capacitance Pickup

Air Temperature Inside Distributor (TA)

It was not possible to record the temperature of the air inside the distributor directly using the above apparatus because the combined hygrometer/temperature probe had to be sited in a small recess in the distributor cap in order to shield it from the HT plasma energy, which placed certain limitations on the data that could be reliably obtained.

The combination of the convective air streams circulating around the surface of the very hot alloy cylinder head due to the action of the spinning rotor arm, and the low thermal conductivity of the distributor cap resin material, ensured that the air inside the cap heated up more quickly than the distributor cap that housed the hygrometer/temperature probe (furthest away from the source of heat).

The shielding effect of the small recess resulted in the temperature probe actually reading the temperature of the distributor cap, and not the temperature of the air inside the cap, but this was ok because the air temperature inside the distributor cap could easily be calculated.

There was also a slight lag in the hygrometer (RH%) readings, but this effect was not thought to be significant since we were more interested in the trend of relative humidity inside the cap as opposed to absolute accuracy.

A theoretical expression for the temperature of the air inside the distributor therefore had to be developed and this process is described in the section 'THEORY' in next section of this article.

THEORY

Using standard physics equations of enthalpy, the heat energy due to conduction through air, and the transfer of heat energy via convection to the distributor cap were calculated. From the recorded temperature of the alloy head and distributor cap it is simple to calculate the temperature of the air inside the distributor.

Symbol Definitions:

t = temperature of air as a function of time ($^{\circ}\text{C}$)
 t_0 = initial temperature of air ($^{\circ}\text{C}$)
 t_{∞} = ambient temperature ($^{\circ}\text{C}$)
 e = natural logarithm base
 h = coefficient of convection $\text{W}/(\text{m}^2\text{K})$
 H = altitude (masl)
 A = surface area (m^2)
 V = Volume of air in distributor (allowing for rotor and losses) (m^3)
 p = density of air (kg/m^3)
 c = specific heat of air (kJ/kgK)
 t = heating time (secs)
 t_{bp} = dry bulb temperature of air ($^{\circ}\text{C}$)
 $t_{bp \text{ min}}$ = minimum dry bulb temperature of air required to initiate condensation ($^{\circ}\text{C}$)
 t_{dp} = dew point temperature of air ($^{\circ}\text{C}$)
 m = mass of air (kg)
 A_o = cross sectional area of OE ventilation (mm^2)
 A_m = cross sectional area of modified ventilation (mm^2)
 r = radius of distributor cap (m)
 d = depth of recess inside distributor (m)
 RPM = engine revolutions per minute during test (rpm)
 w = angular rotation of camshaft (radians/sec)
 v = angular velocity of air due to rotation of camshaft and rotor (rad/sec)
 Q = amount of conductive heat energy (J)
 Q_c = amount of convective heat energy (J)
 DT = change in temperature of air inside distributor ($^{\circ}\text{C}$, or K)
 TA = temperature of air inside distributor ($^{\circ}\text{C}$)
 TA_0 = initial temperature of air inside distributor ($^{\circ}\text{C}$)
 TS = temperature of surface of alloy recess ($^{\circ}\text{C}$)

Values of Constants:

$c =$	1100	$\text{J}/\text{kg.K}$	$V =$	0.0004	m^3
$p =$	1.225	kg/m^3	$m =$	0.0005	kg
$A_o =$	9	mm^2	$D =$	85	mm
$A_m =$	varies	mm^2	$d =$	40	mm
$h =$	25	$\text{W}/(\text{m}^2\text{K})$	$\text{RPM} =$	750	
$A =$	0.0056	m^2	$w =$	78.5	rad/sec
			$v = w \cdot r =$	3.34	m/s

Assumptions:

Steady-state conditions .
 Uniform surface temperature.
 Negligible radiation inside the cap.
 Forced convection due to rotating rotor allowed for in calculation of (h).
 Volume of rotor occupies 37.5% of total free volume of distributor.

Thermal losses in the OEM distributor are assumed to be negligible.
 Cross ventilation in the OEM distributor is assumed to be negligible due to the poor positioning of the discrete vents.

Thermal losses in the modified distributor are taken in to account as follows:
 It is assumed that the additional ventilation slots allow cross flow ventilation to occur.

A proportion of warm air in the distributor is displaced by cooler air via the lower vents and expulsion of the warm air via the top vents by convection. The displacement of some of the warm air inside the distributor is allowed for by assuming that the effective mass of the air being heated in the distributor is increased by the ratio of the cross section of the new ventilation to original.

Formula of Rate of Change of Temperature (°C):

$$t = (t_o - t_{\infty}) * e^{h.A/(p.c.V)*t} + t_{\infty}$$

Formula of Coefficient of Convection, h (W/(m²K)) [2]:

$$h = 10.45 - v + 10 v^{1/2} \text{ valid for } 2 < v < 20 \text{ m/s}$$

Typical values of h (W/(m²K)) [2]:

Free Convection - air, gases and dry vapours : 0.5 - 1000 (W/(m²K))
 Free Convection - water and liquids: 50 - 3000 (W/(m²K))
 Forced Convection - air, gases and dry vapours: 10 - 1000 (W/(m²K))
 Forced Convection - water and liquids: 50 - 10000 (W/(m²K))
 Forced Convection - liquid metals: 5000 - 40000 (W/(m²K))
 Boiling Water : 3.000 - 100.000 (W/(m²K))
 Condensing Water Vapour: 5.000 - 100.000 (W/(m²K))

Heat Energy, Q (J) and Convective Heat Transfer, Qc (J):

The amount of heat (Q) required to increase the temperature of air:

$$Q = c m \Delta T$$

The convective heat (Qc) transferred between a hot surface and cold air [2]:

$$Qc = h.A (T_s - T_a)$$

Equating the heat of convection (Q_c) transferred to air passing over the hot alloy surface to the heat of conduction (Q) to heat the air up by ΔT :

$$Q = Q_c$$

Defining Functions:

$$f(T) = c. m. f(t) / h.A$$

$$\Delta T = T_A - T_{A0}$$

Derivation of Equation for Air Temperature inside Distributor, T_A ($^{\circ}C$)

Equating $Q = Q_c$:

$$c. m. f(t). \Delta T_A = h. A. (T_S - T_A)$$

Allowing for rate of heating of air:

$$T_A = T_S - c. m. \Delta T_A. f(t) / (h. A)$$

where:

$$f(t) = e^{h.A/(p.c.V)*t}$$

Rearranging in terms of T_A :

$$T_A = T_S - (c. m. f(t). \Delta T / h. A)$$

Substituting terms:

$$T_A = T_S - f(T). \Delta T$$

$$T_A = T_S - f(T). (T_A - T_{A0})$$

$$T_A = T_S - (f(T). T_A) + (f(T). T_{A0})$$

$$T_A + (f(T). T_A) = T_S + (f(T). T_{A0})$$

$$T_A. (1 + f(T)) = T_S + (f(T). T_{A0})$$

$$T_A = (T_S + (f(T). T_{A0})) / (1 + f(T))$$

Data Analysis

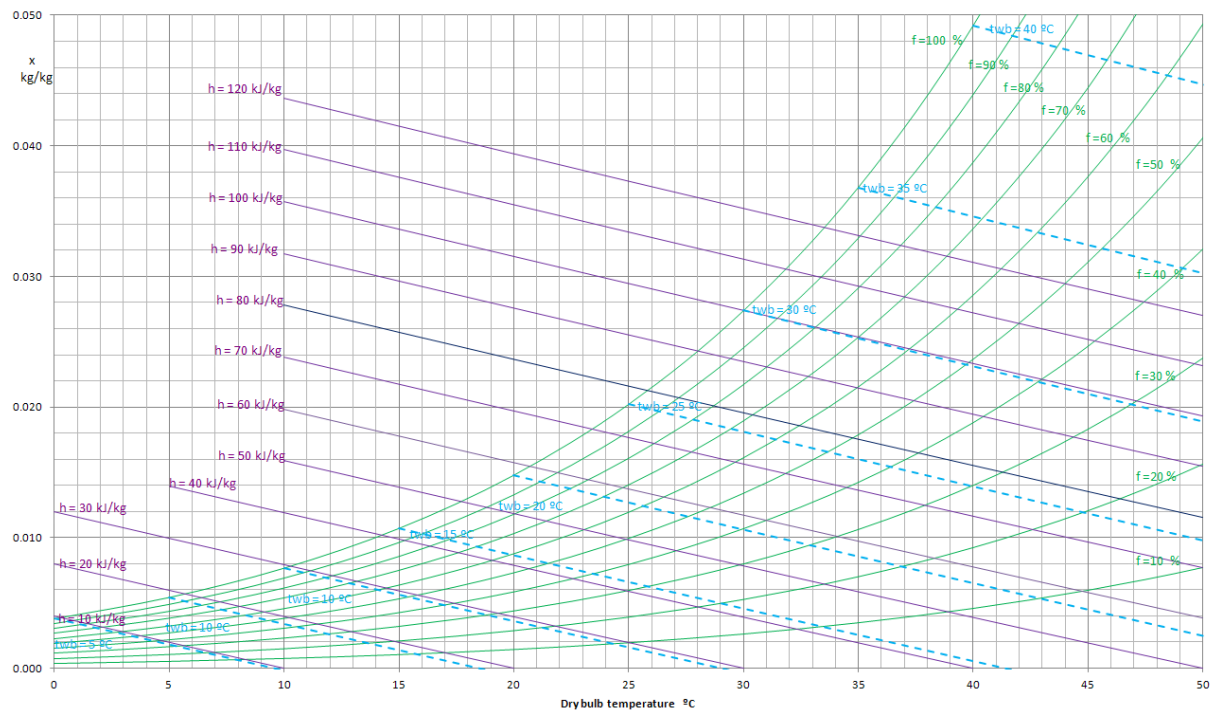


Figure 13 Psychrometric Chart for Altitude = 52m a.s.l.

The following data was recorded: - Ambient relative humidity (RHA), ambient temperature (t_{∞}), altitude (H), time (minutes), relative humidity of air inside distributor cap (RHC), temperature of distributor cap (TC), and temperature of alloy recess (TS), speed of rotation of rotor (RPM), radius of distributor cap (r), depth of recess in distributor cap (d), cross sectional area of ventilation of OEM distributor cap (A_o), cross sectional area of ventilation of modified distributor cap (A_m), specific heat of air (c), and the density of air (ρ), and engine misfires denoted by a drop in coil output voltage (kV).

The temperature of the air inside the distributor (TA) was calculated for each increment of time (t) using the equation:

$$TA = (TS + (f(T) \cdot TA_0)) / (1 + f(T))$$

Using the psychrometric equations for air, the moisture concentration of air (kg/kg dry air) inside the distributor cap was also calculated.

By assigning a value for the dew point temperature (tdp) of air equal to the recorded distributor cap temperature, the minimum dry bulb temperature of air required to initiate condensation on the distributor cap was calculated using the psychrometric equations for air for the following parameters a) relative humidity (RH %), b) assigned dew point temperature, and c) altitude (H).

The minimum dry bulb (tbp min) temperature was then compared to the calculated temperature of the air inside the distributor cap (TA) to determine the risk of condensation. Graphical plots were created of relative humidity verses time, moisture concentration verses time, and temperature of the air inside the distributor against time and analysed, and conclusions drawn.

RESULTS

1) RUN #1 - 27 Aug 2017 - SUMMER CONDITIONS - CONTROL TEST - NO MISFIRE

RUN #1 - 2017-08-27 Garage RH = 30% Ambient T = 15.0 deg C Altitude = 52 m.a.s.l.
 Ambient RH = 50%

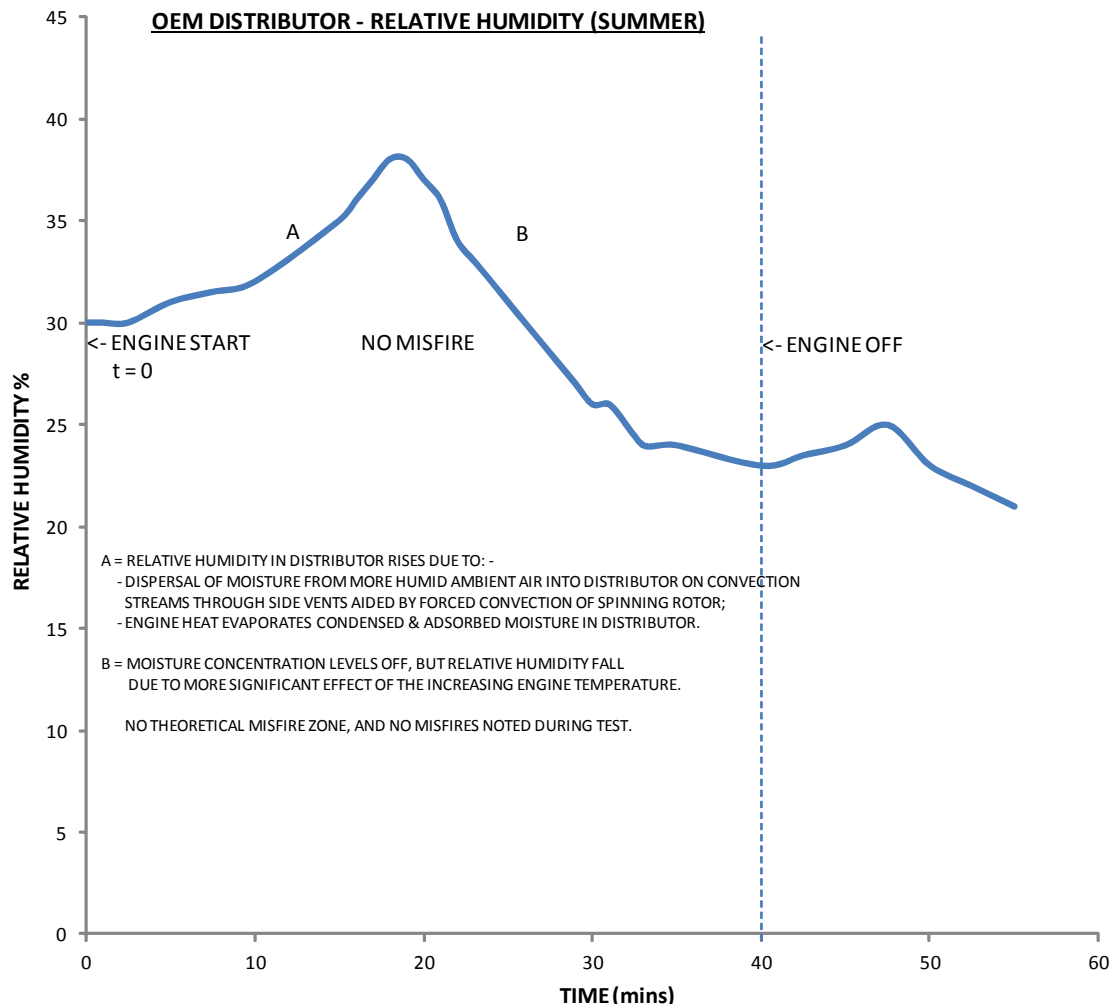


Figure 14 RUN #1 - 27 Aug 2017 - Graph of RH % v's Time

The drop in relative humidity starting at approximately $t = 20$ minutes suggests the onset of some condensation inside the cap. However when we examine the graph of moisture concentration of the air against time on the next page, we can see that the moisture concentration does not drop significantly. Essentially condensation dehumidifies the air, so condensation is synonymous with a drop in moisture concentration. Since there was no significant drop in moisture concentration of the air inside the distributor, we can deduce from this that condensation did not occur.

If we refer to the data in the Appendix we can see that the calculated temperature of the air inside the distributor cap (T_A) is less than the calculated minimum dry bulb (tdp min) temperature required to initiate condensation. This also indicates that condensation did not occur and therefore there was no theoretical risk of misfire, which concurs with the output from the UEI ADL 7100 scope traces. No misfires were recorded.

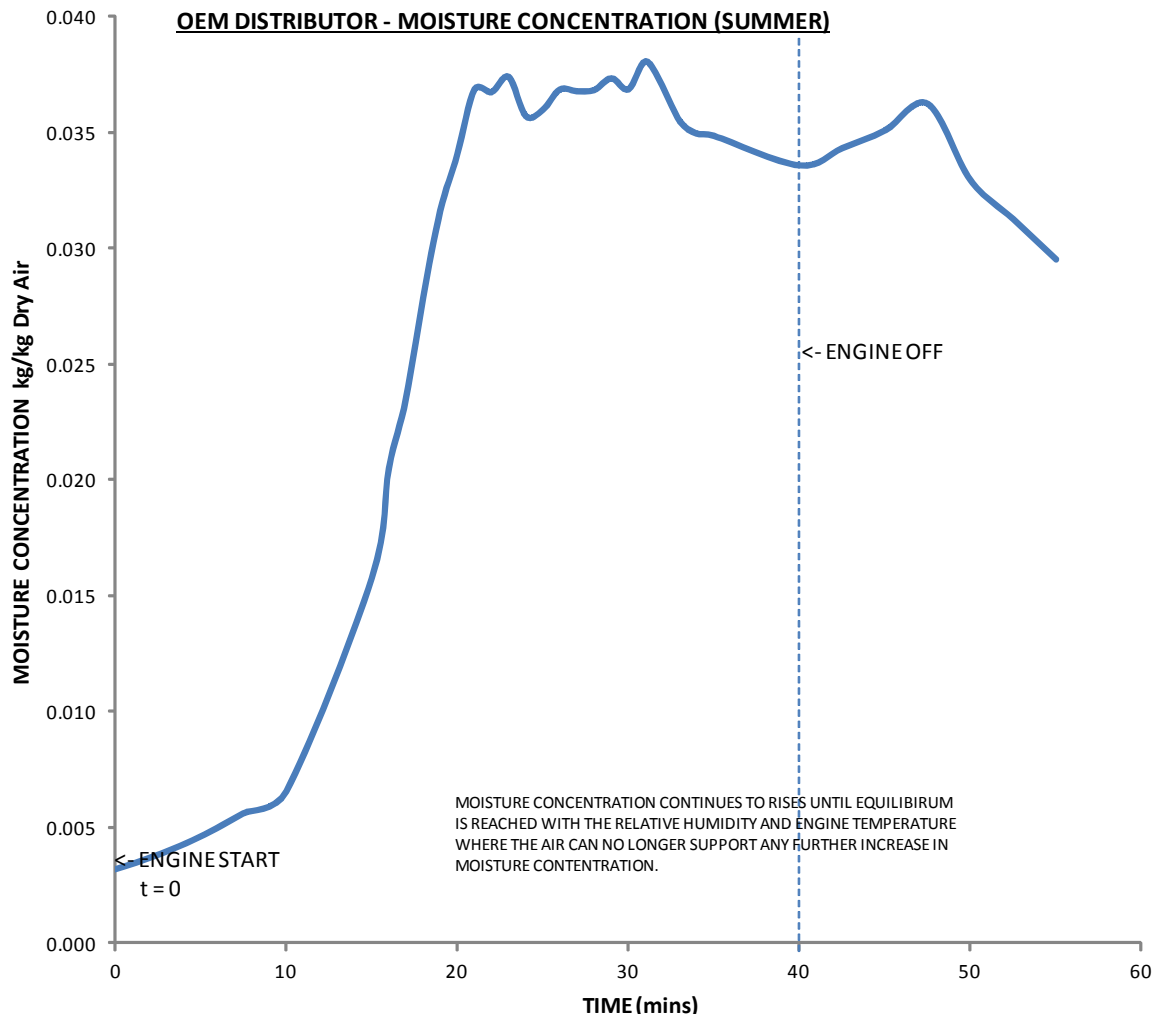


Figure 15 RUN #1 - 27 Aug 2017 - Graph of Moisture Concentration v's Time

A peak moisture concentration of 0.037 kg/kg dry air was reached at t = 21 minutes. The peak fell off slightly to approximately 0.034 kg/kg dry air at t = 40 minutes at which point the engine was switched off.

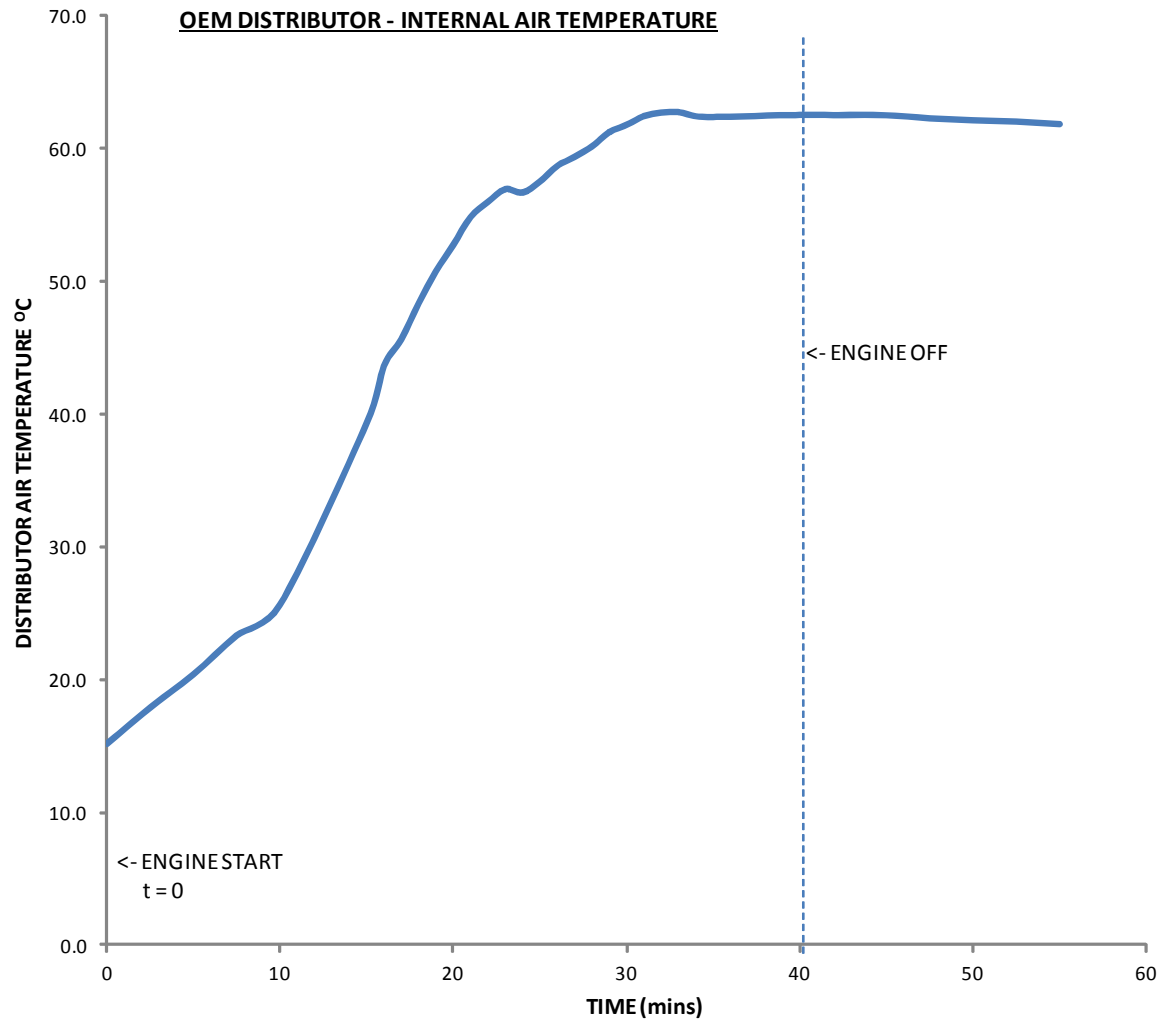


Figure 16 RUN #1 - 27 Aug 2017 - Graph of Distributor Air Temperature v's Time

The temperature of the air inside the distributor at t = 0 minutes at the point of engine start was 15 deg C.

The peak temperature of the air inside the distributor at t = 30 minutes was 63 deg C.

2) RUN #2 - 10 Feb 2018 - WINTER CONDITIONS - OCCURRENCE OF MISFIRE

RUN #2 - 2018-02-10 Garage RH = 40% Ambient T = 5.0 deg C Altitude = 52 m.a.s.l.
 Ambient RH = 65%

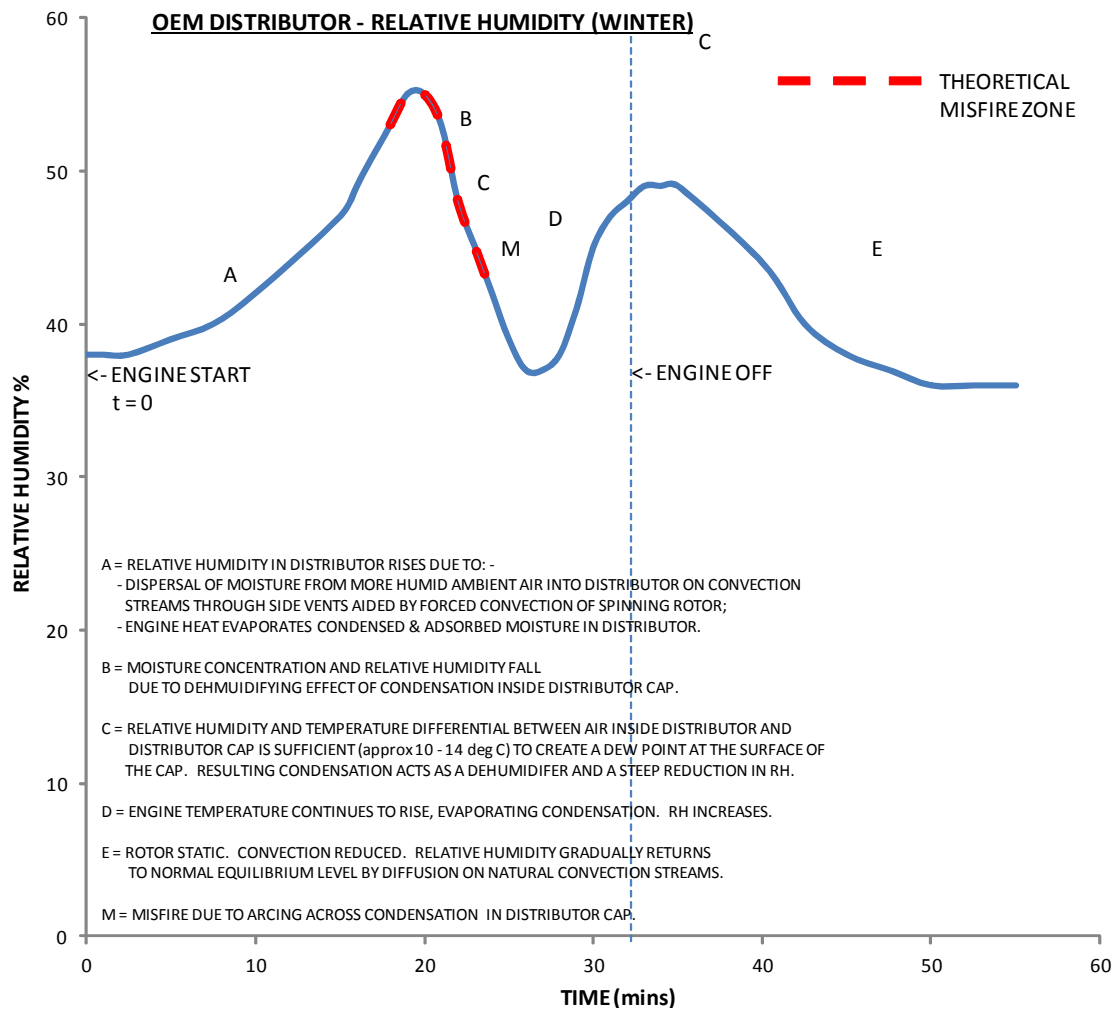


Figure 17 RUN #2 - 10 Feb 2018 - Graph of RH % v's Time

The drop in relative humidity starting at approximately t = 20 minutes aligns with the significant drop in moisture concentration of the air inside the distributor shown in the graph on the next page. We can deduce from this that condensation occurred inside the distributor.

If we refer to the data in the Appendix we can see that the calculated temperature of the air inside the distributor cap (TA) was greater than the calculated minimum dry bulb (tbp min) temperature required to initiate condensation in this instance (denoted by the red dotted line). This also suggests that condensation occurred and that there was a significant theoretical risk of misfire, which concurs with the output from the UEI ADL 7100 scope traces. Misfires were recorded, and are denoted on the graph by 'M'.

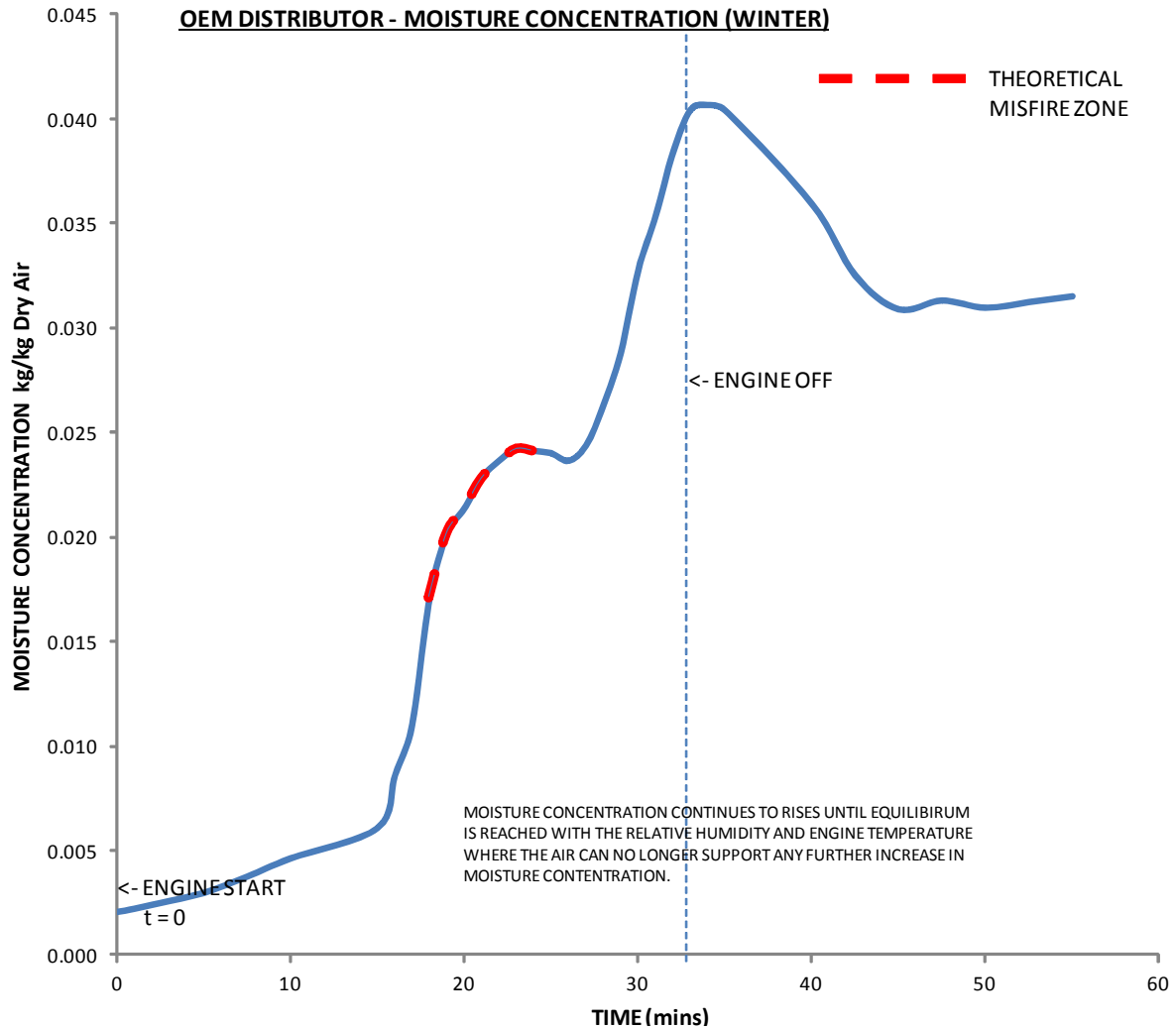


Figure 18 RUN #2 - 10 Feb 2018 - Graph of Moisture Concentration v's Time

A peak moisture concentration of 0.041 kg/kg dry air was reached at $t = 34$ minutes at the point that the engine was switched off. The peak fell off to approximately 0.031 kg/kg dry air at $t = 41$ minutes at which point the engine was switched off.

Of note is the drop in moisture concentration at $t = 20$ minutes is out of phase with and lags behind the drop in relative humidity. In this case the initial drop in relative humidity is related to the increase in distributor air temperature and not condensation in the distributor. Consequently, although there is a theoretical risk of misfire at the onset of the drop in relative humidity, the misfire is unlikely to occur until just before the drop in moisture concentration.

If the drop in relative humidity and moisture concentration are in phase with each other, the theoretical risk of misfire would be high from the onset of the drop in relative humidity.

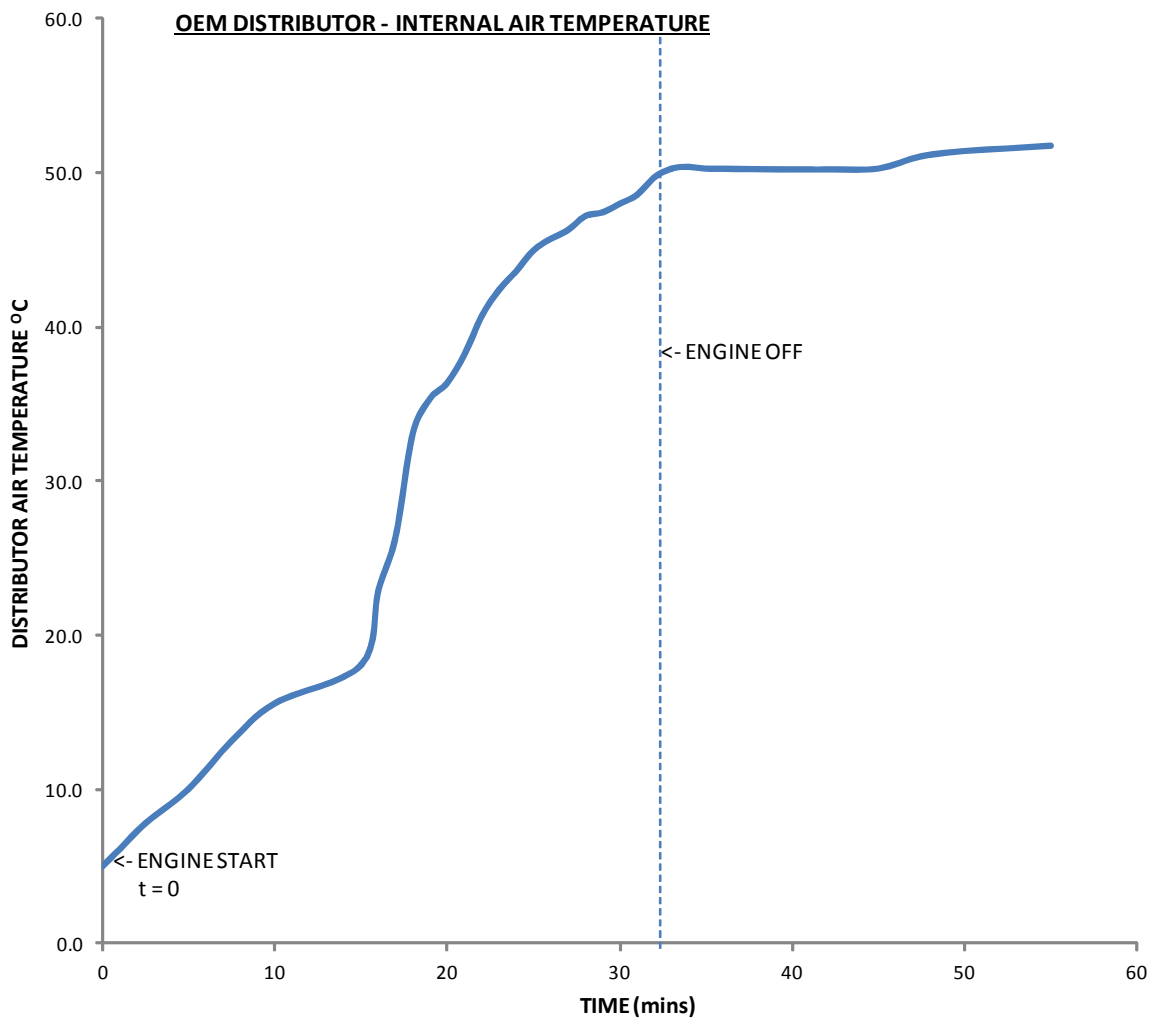


Figure 19 RUN #2 - 10 Feb 2018 - Graph of Distributor Air Temperature v's Time

The temperature of the air inside the distributor at t = 0 minutes at the point of engine start was 8 deg C.

The peak temperature of the air inside the distributor reached a plateau of 50 deg C at t = 32 minutes, and then increased slowly to 55 deg C at t = 60 minutes.

3) RUN #3 - 11 Feb 2018 - WINTER CONDITONS - OCCURRENCE OF MISFIRE

To examine the warm up and cooling phases inside the distributor cap taking into account the moisture build up from run #2.

RUN #3 - 2018-02-11 Garage RH = 40% Ambient T = 8.0 deg C Altitude = 52 m.a.s.l
 Ambient RH = 65%

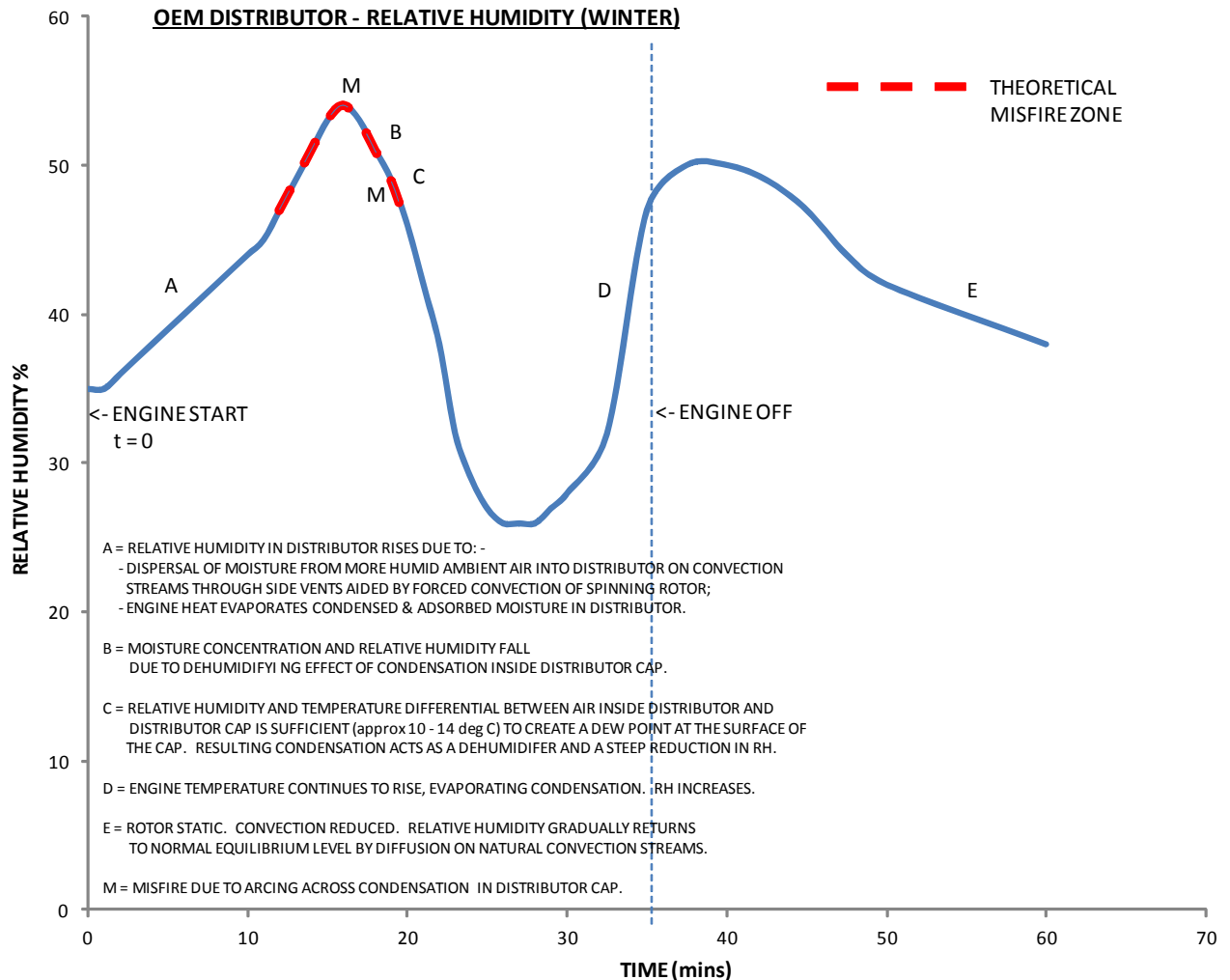


Figure 20 RUN #3 - 11 Feb 2018 - Graph of RH % v's Time

The drop in relative humidity starting at approximately t = 18 minutes aligns with the significant drop in moisture concentration of the air inside the distributor shown in the graph on the next page. We can deduce from this that condensation occurred inside the distributor.

If we refer to the data in the Appendix we can see that the calculated temperature of the air inside the distributor cap (TA) was greater than the calculated minimum dry bulb (tbp min) temperature required to initiate condensation in this instance (denoted by the red dotted line). This also suggests that condensation occurred and that there was a significant theoretical risk of misfire, which concurs with the output from the UEI ADL 7100 scope traces. Misfires were recorded, and are denoted on the graph by 'M'.

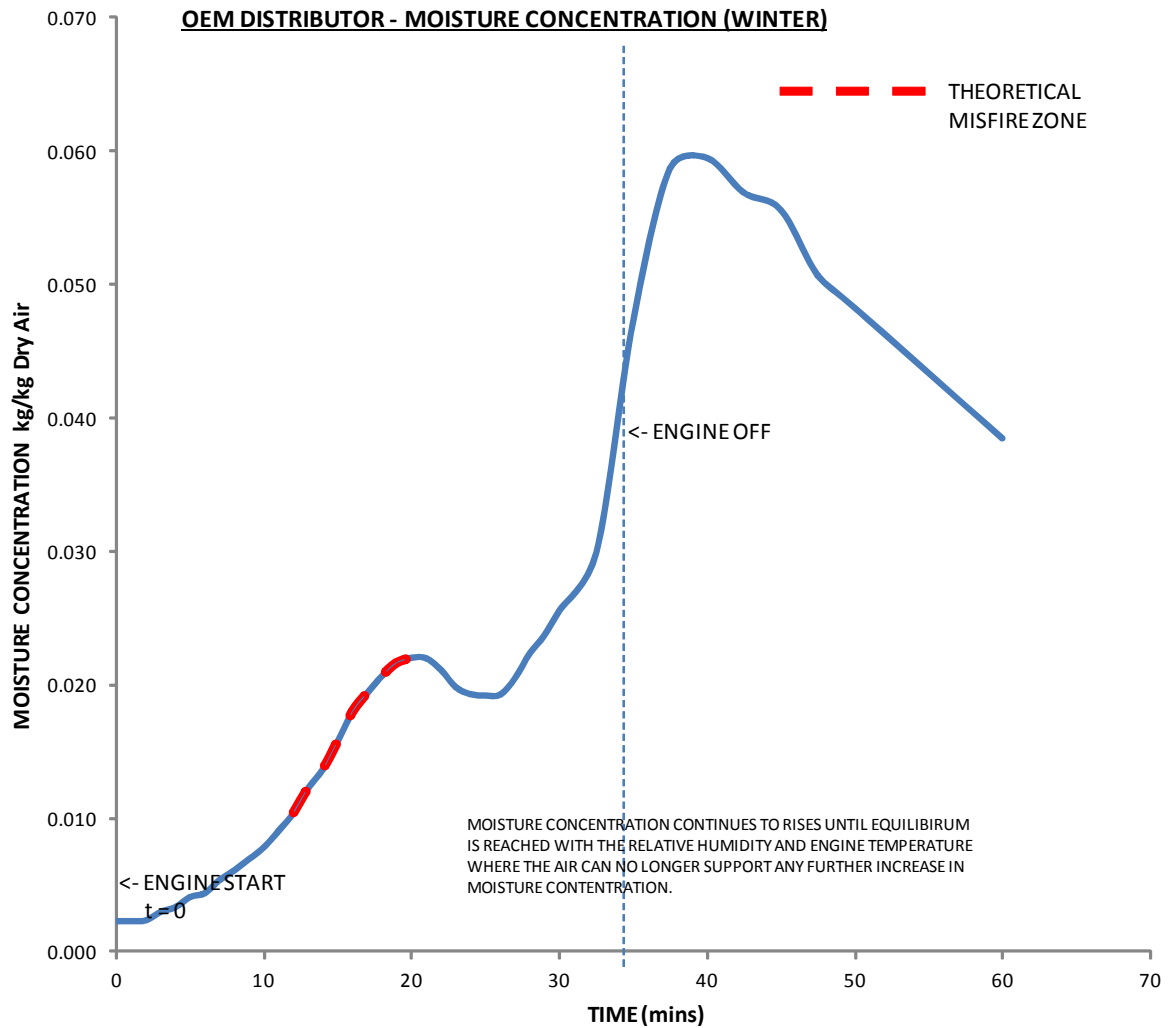


Figure 21 RUN #3 - 11 Feb 2018 - Graph of Moisture Concentration v's Time

A peak moisture concentration of 0.060 kg/kg dry air was reached at $t = 40$ minutes, approximately 6 minutes after the engine was switched off. The peak fell off to approximately 0.038 kg/kg dry air at $t = 60$ minutes.

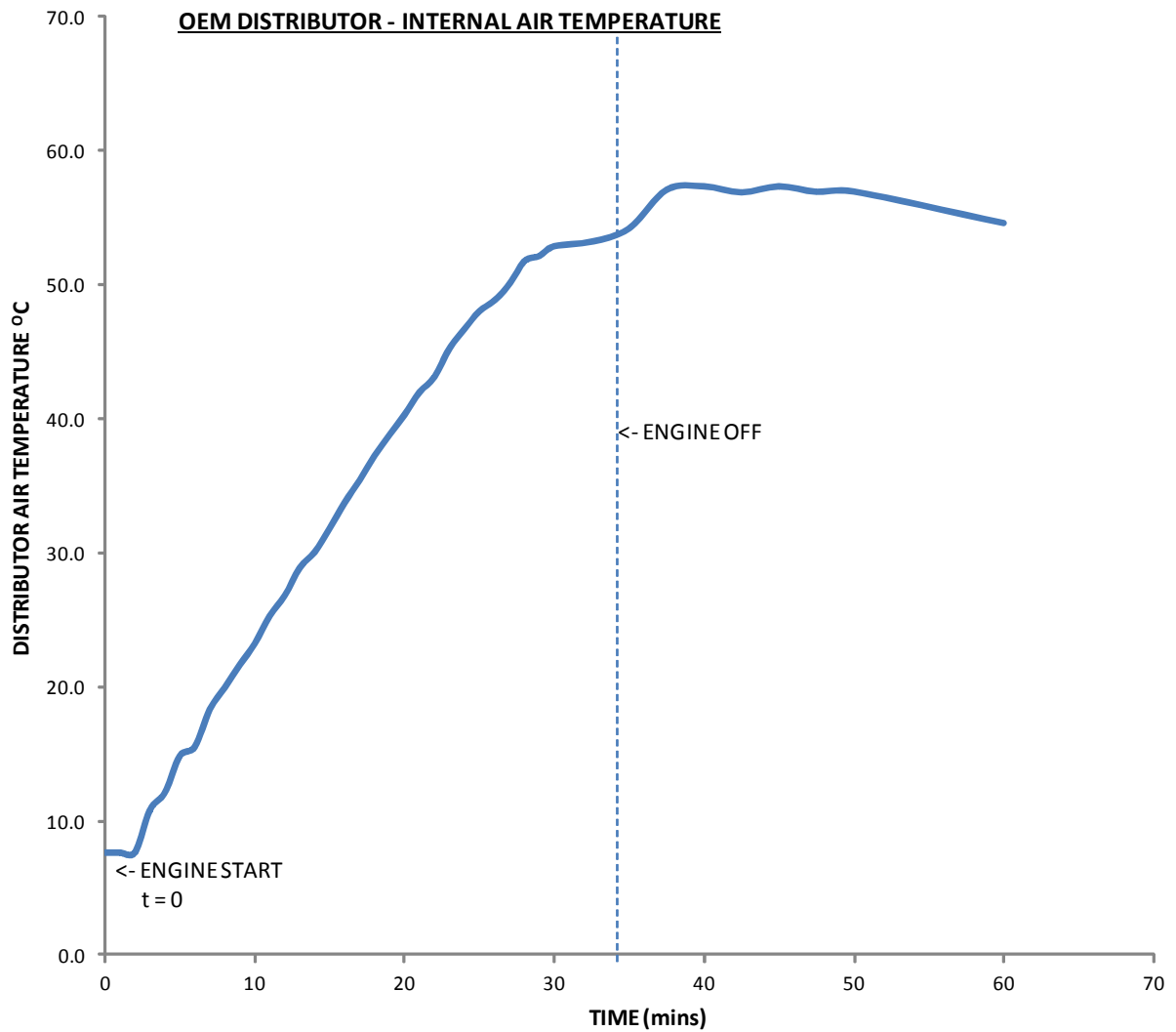


Figure 22 RUN #3 - 11 Feb 2018 - Graph of Distributor Air Temperature v's Time

The temperature of the air inside the distributor at t = 0 minutes at the point of engine start was 8 deg C.

The peak temperature of the air inside the distributor reached a plateau of 58 deg C at t = 38 minutes.

4) RUN #4 - 12 Feb 2018 - WINTER CONDITIONS - OCCURRENCE OF MISFIRE

To examine the effects of a short run, turning the engine off for a brief period, and restarting again. Anecdotally we know that this produces the worst conditions for misfire

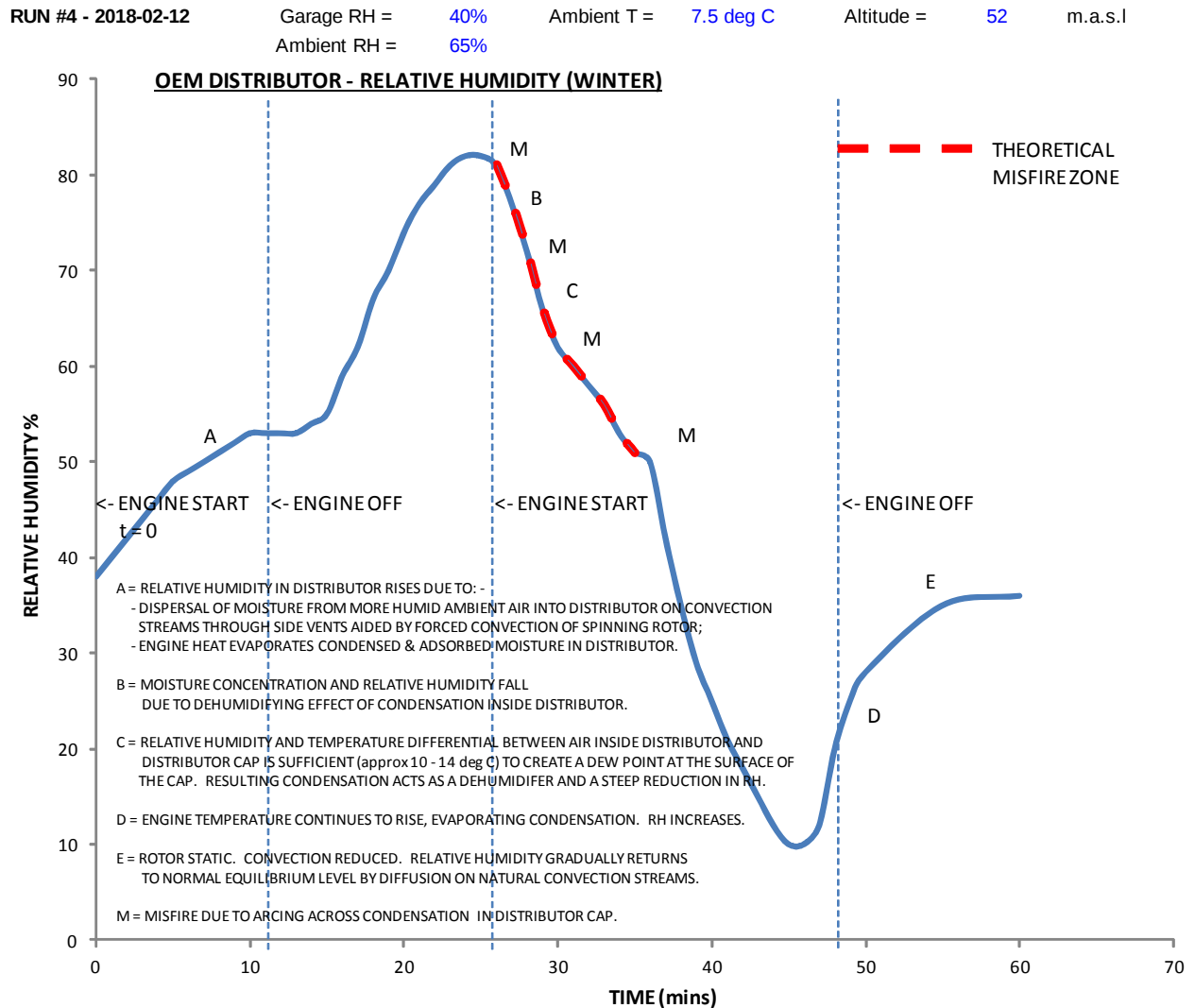


Figure 23 RUN #4 - 12 Feb 2018 - Graph of RH % v's Time

The drop in relative humidity starting at approximately t = 24 minutes aligns with the significant drop in moisture concentration of the air inside the distributor shown in the graph on the next page. We can deduce from this that condensation occurred inside the distributor.

If we refer to the data in the Appendix we can see that the calculated temperature of the air inside the distributor cap (TA) was greater than the calculated minimum dry bulb (tbp min) temperature required to initiate condensation in this instance (denoted by the red dotted line). This also suggests that condensation occurred and that there was a significant theoretical risk of misfire, which concurs with the output from the UEI ADL 7100 scope traces. Misfires were recorded, and are denoted on the graph by 'M'.

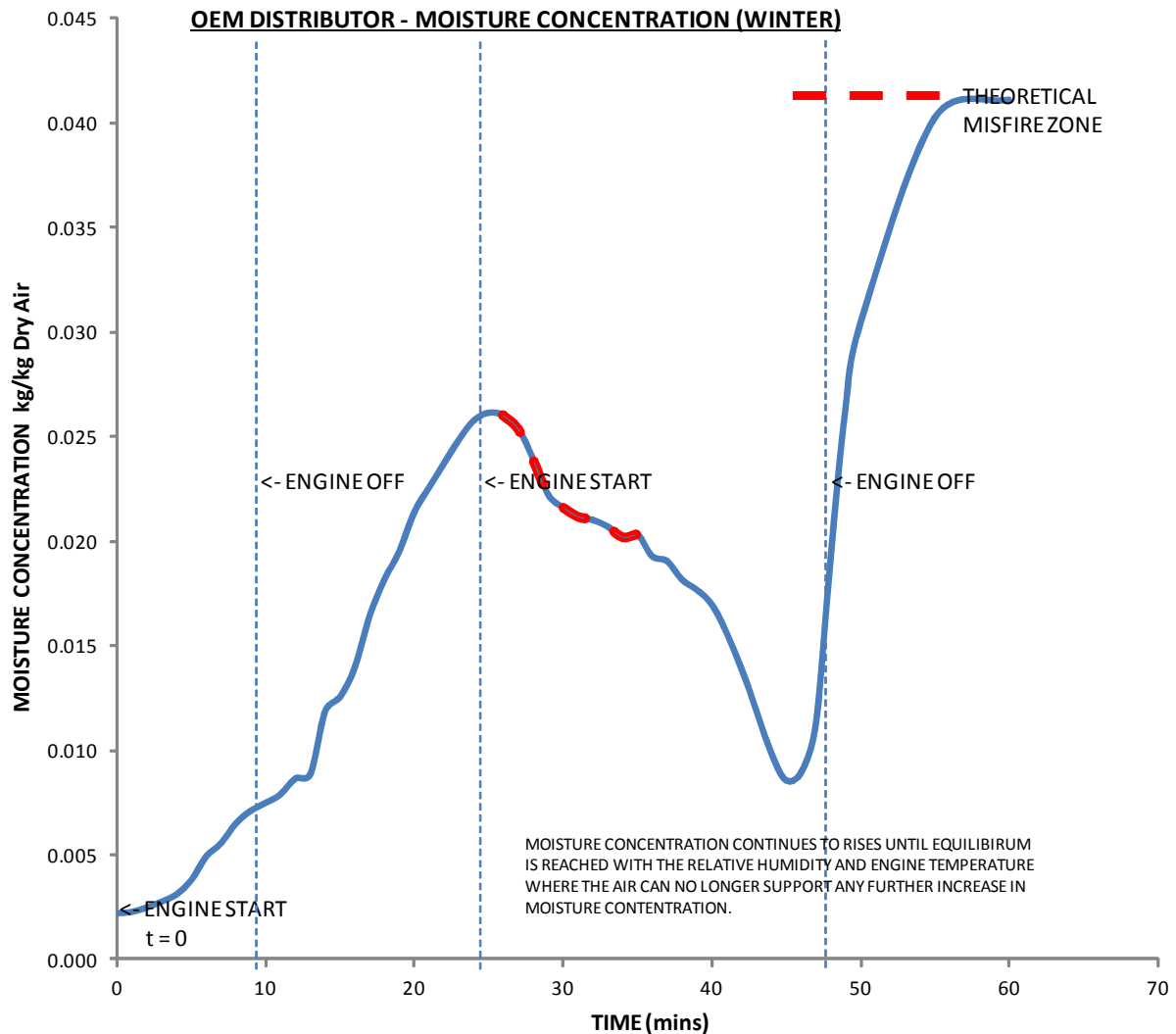


Figure 24 RUN #4 - 12 Feb 2018 - Graph of Moisture Concentration v's Time

A peak moisture concentration of 0.042 kg/kg dry air was reached at $t = 56$ minutes.

The negative (downward) gradient of the RH% v's time graph after the engine is restarted for the second time at $t = 26$ minutes is significantly steeper than the gradient in previous tests.

Furthermore, the reduction in moisture concentration at this point is more extensive than previous tests. This indicates that a greater amount of condensation occurred at this point in the test compared to previous tests, and we can deduce from this that the engine would have been at much greater risk of misfire.

The misfires that we recorded in this test run were significantly worse to the point that the engine almost stalled a number of times. This aligns very well with the theoretical predictions and also anecdotal evidence that restarting the engine after it has been switched off for a brief period can make the misfiring worse. Note also that the drop in relative humidity and moisture concentration are in phase with each other, therefore representing a high risk of misfire from the onset of the drop in relative humidity at $t = 26$ minutes.

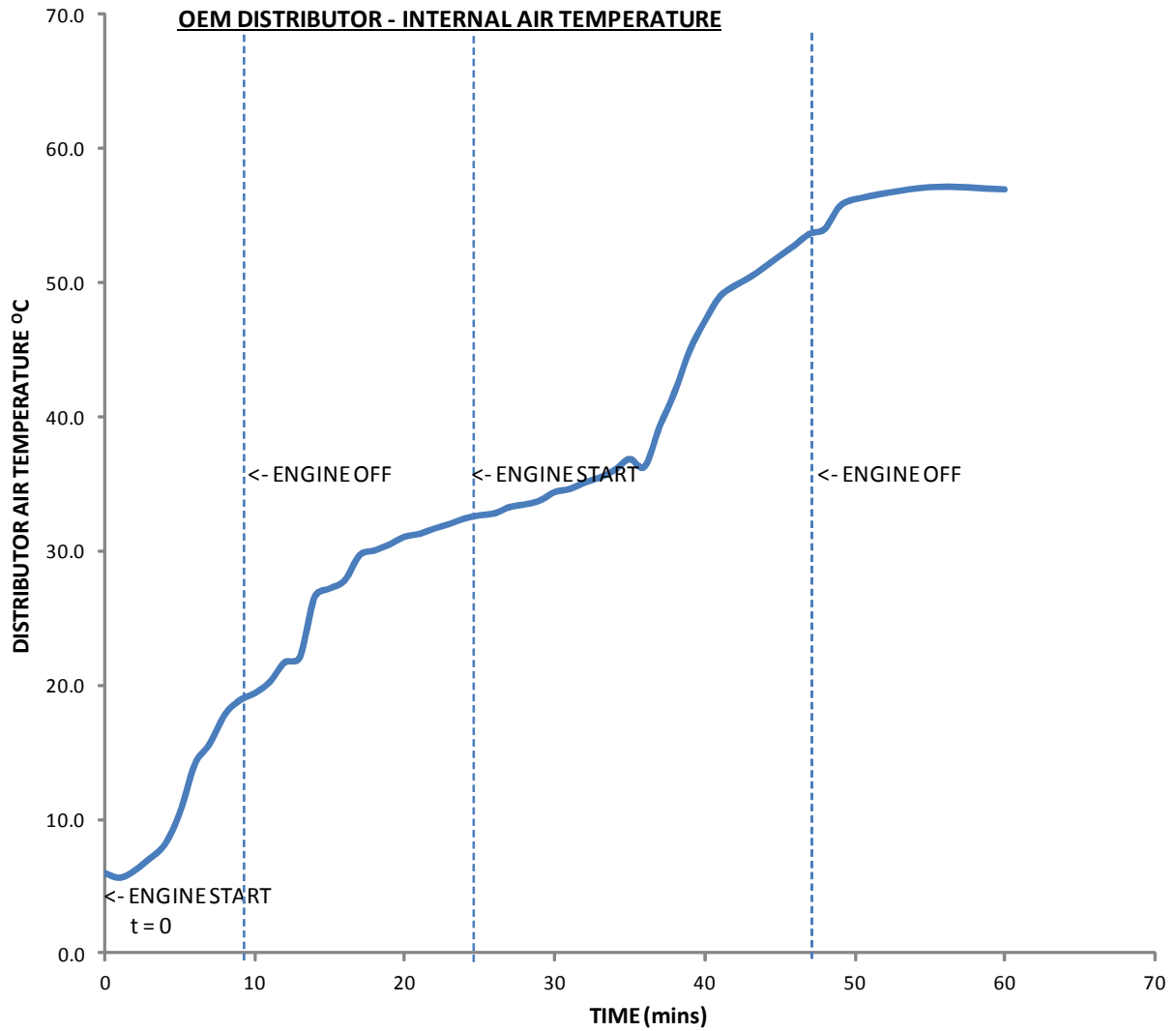


Figure 25 RUN #4 - 12 Feb 2018 - Graph of Distributor Air Temperature v's Time

The temperature of the air inside the distributor at t = 0 minutes at the point of engine start was 8 deg C.

The peak temperature of the air inside the distributor reached a plateau of 58 deg C at t = 53 minutes.

5) RUN #5 - 13 Feb 2018 - WINTER CONDITIONS - OCCURRENCE OF MISFIRE

To examine the long term changes inside the distributor while the engine is idling for 90 minutes.

RUN #5 - 2018-02-13 Garage RH = 40% Ambient T = 8.0 deg C Altitude = 52 m.a.s.l.
 Ambient RH = 65%

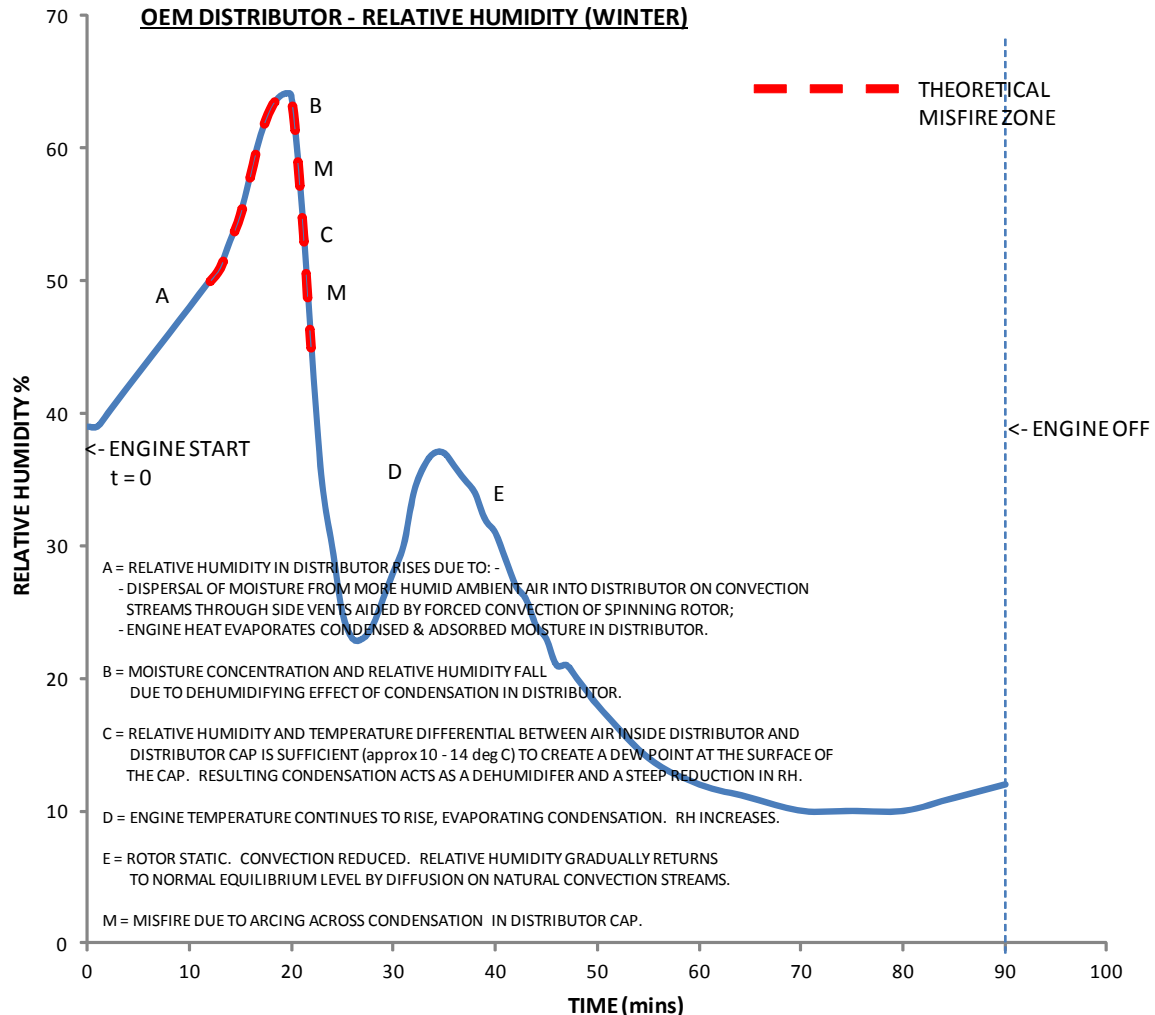


Figure 26 RUN #5 - 13 Feb 2018 - Graph of RH % v's Time

The drop in relative humidity starting at approximately t = 20 minutes aligns with the significant drop in moisture concentration of the air inside the distributor shown in the graph on the next page. We can deduce from this that condensation occurred inside the distributor.

If we refer to the data in the Appendix we can see that the calculated temperature of the air inside the distributor cap (TA) was greater than the calculated minimum dry bulb (tdp min) temperature required to initiate condensation in this instance (denoted by the red dotted line). This also suggests that condensation occurred and that there was a significant theoretical risk of misfire, which concurs with the output from the UEI ADL 7100 scope traces. Misfires were recorded, and are denoted on the graph by 'M'.

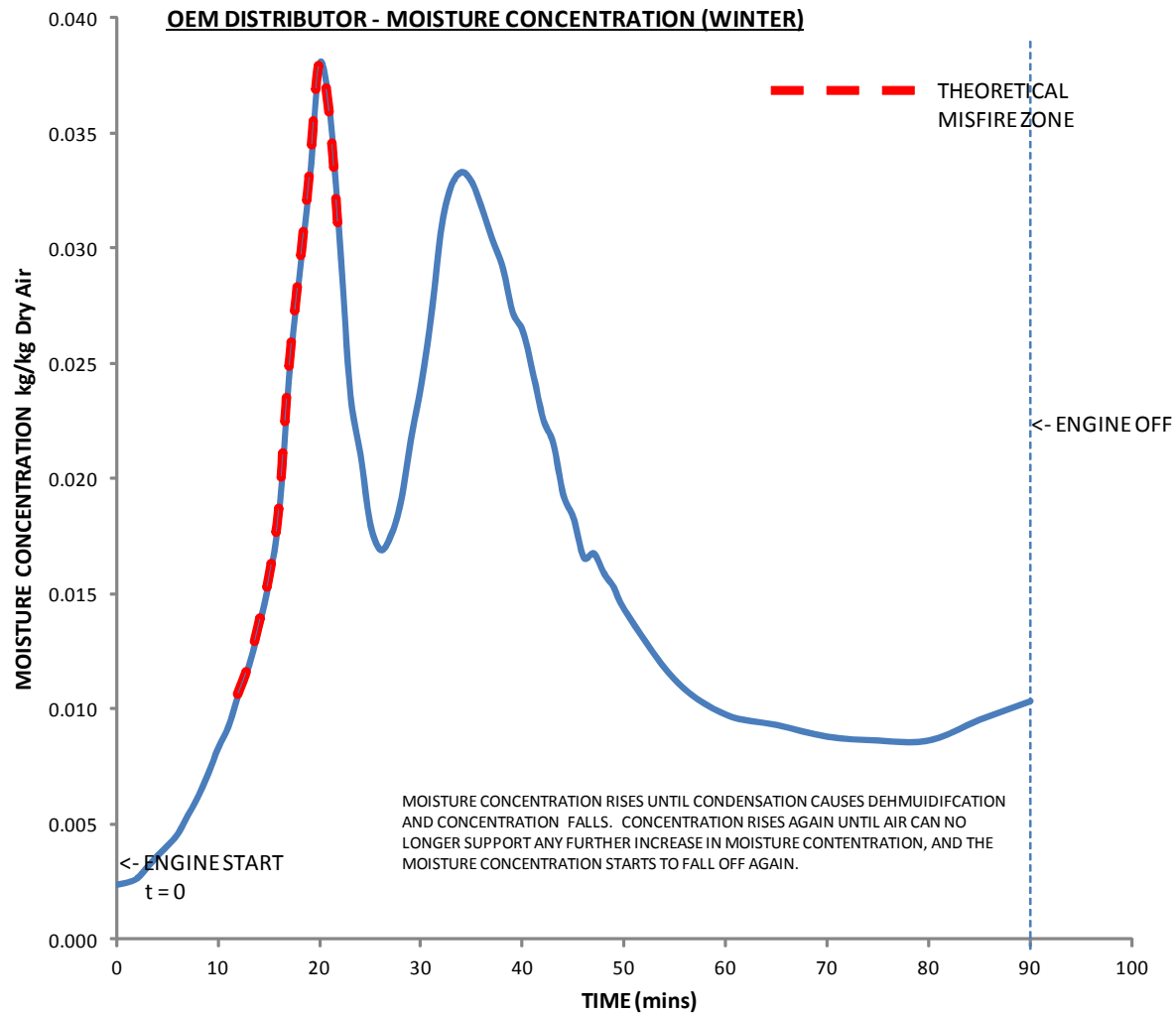


Figure 27 RUN #5 - 13 Feb 2018 - Graph of Moisture Concentration v's Time

A peak moisture concentration of 0.037 kg/kg dry air was reached at t = 20 minutes. The peak fell off to approximately 0.017 kg/kg dry air at t = 26 minutes, and then rose again to 0.03 kg/kg dry air at t = 33 minutes.

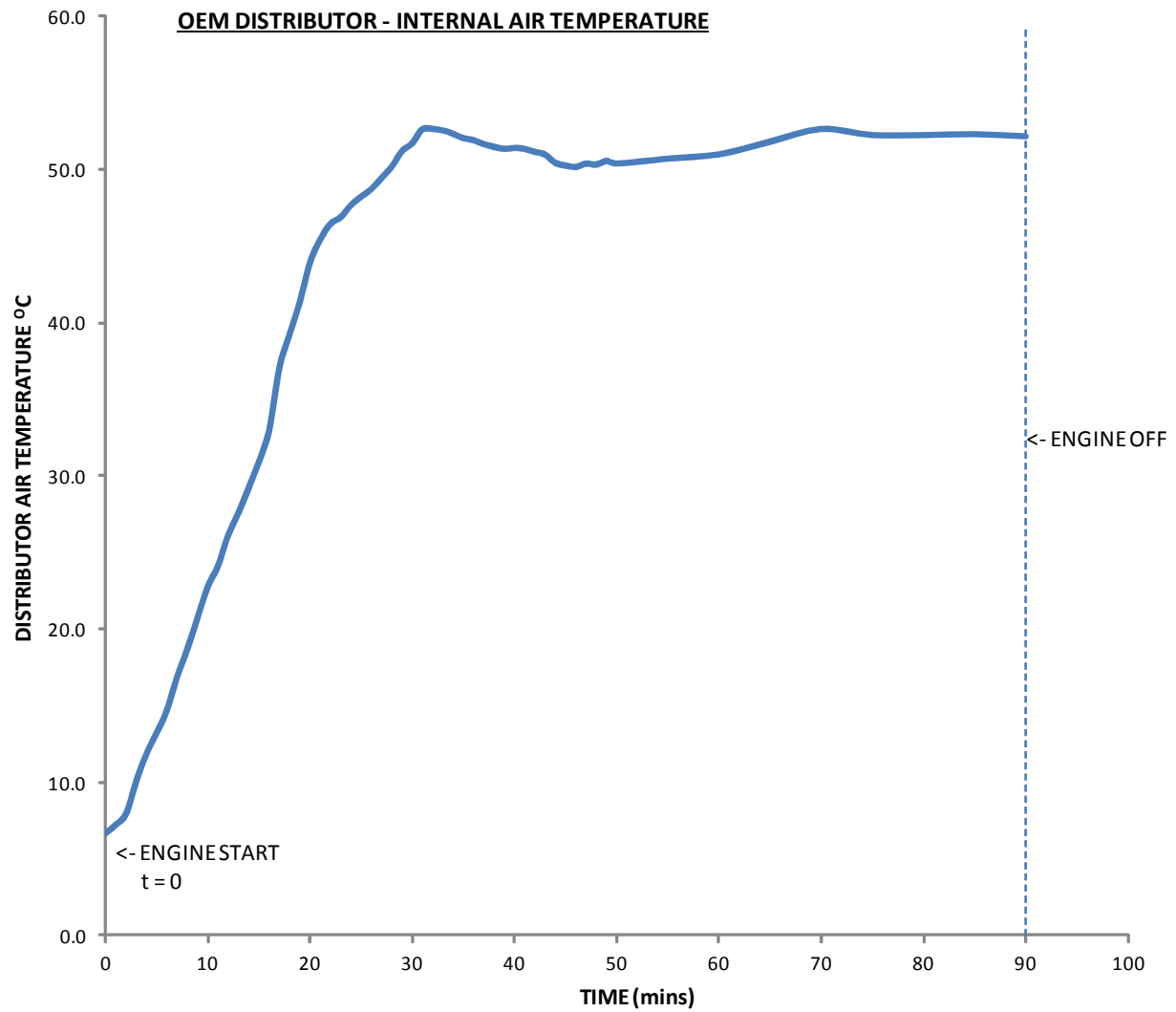


Figure 28 RUN #5 - 13 Feb 2018 - Graph of Distributor Air Temperature v's Time

The temperature of the air inside the distributor at t = 0 minutes at the point of engine start was 8 deg C.

The peak temperature of the air inside the distributor reached a plateau of 53 deg C at t = 32 minutes.

6) RUN #6 - 13 Feb 2018 - MODIFIED DISTRIBUTOR CAP TYPE 1 - OCCURRENCE OF MISFIRE

To examine Modification Type #1 - a single row of additional slot vents near the top of the cap.

RUN #6 - 2018-02-13 Garage RH = 40% Ambient T = 8.0 deg C Altitude = 52 m.a.s.l.
 Ambient RH = 65%

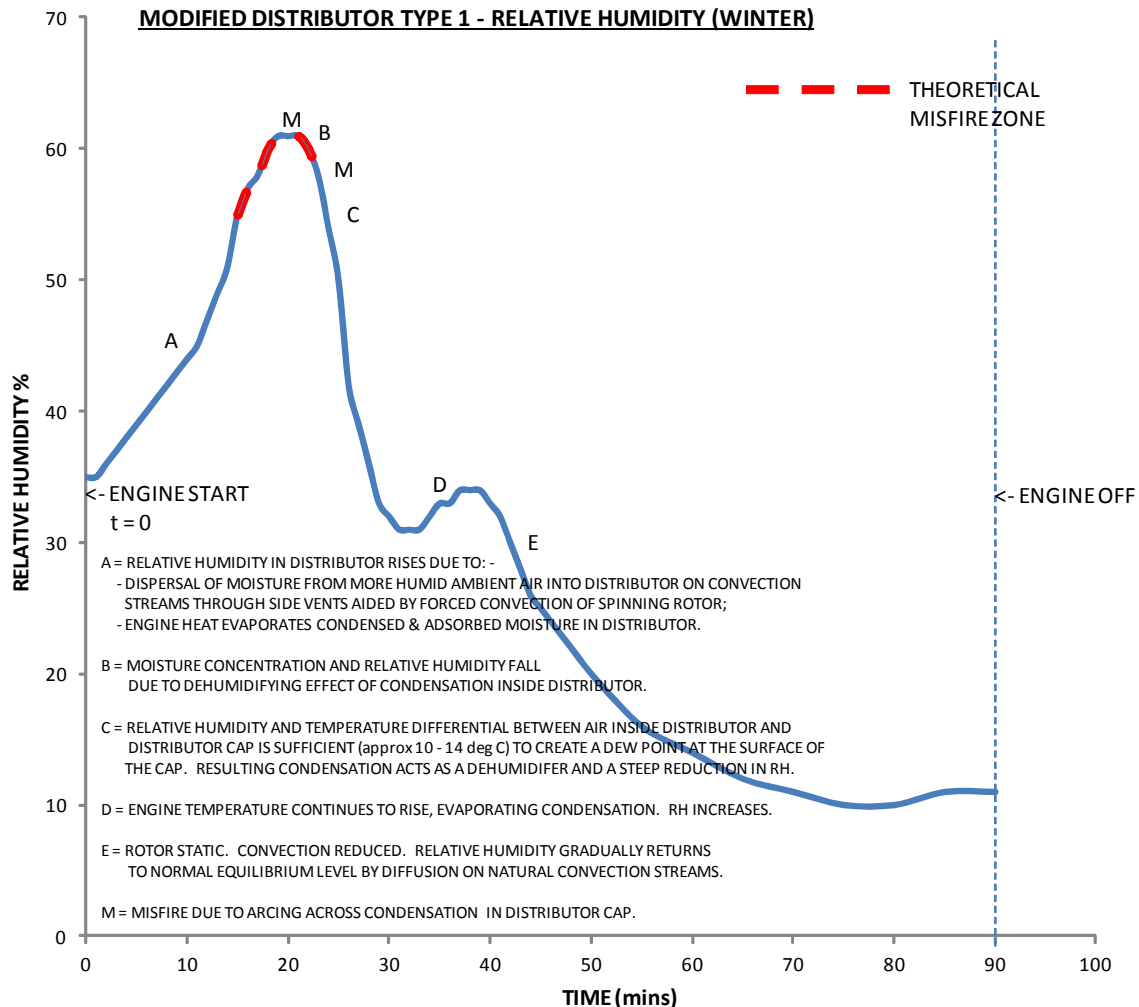


Figure 29 RUN #6 - 13 Feb 2018 - Graph of RH % v's Time

The drop in relative humidity starting at approximately t = 20 minutes aligns with the significant drop in moisture concentration of the air inside the distributor shown in the graph on the next page. We can deduce from this that condensation occurred inside the distributor.

If we refer to the data in the Appendix we can see that the calculated temperature of the air inside the distributor cap (TA) was greater than the calculated minimum dry bulb (tdp min) temperature required to initiate condensation in this instance (denoted by the red dotted line). This also suggests that condensation occurred and that there was a significant theoretical risk of misfire, which concurs with the output from the UEI ADL 7100 scope traces. Misfires were recorded, and are denoted on the graph by 'M'.

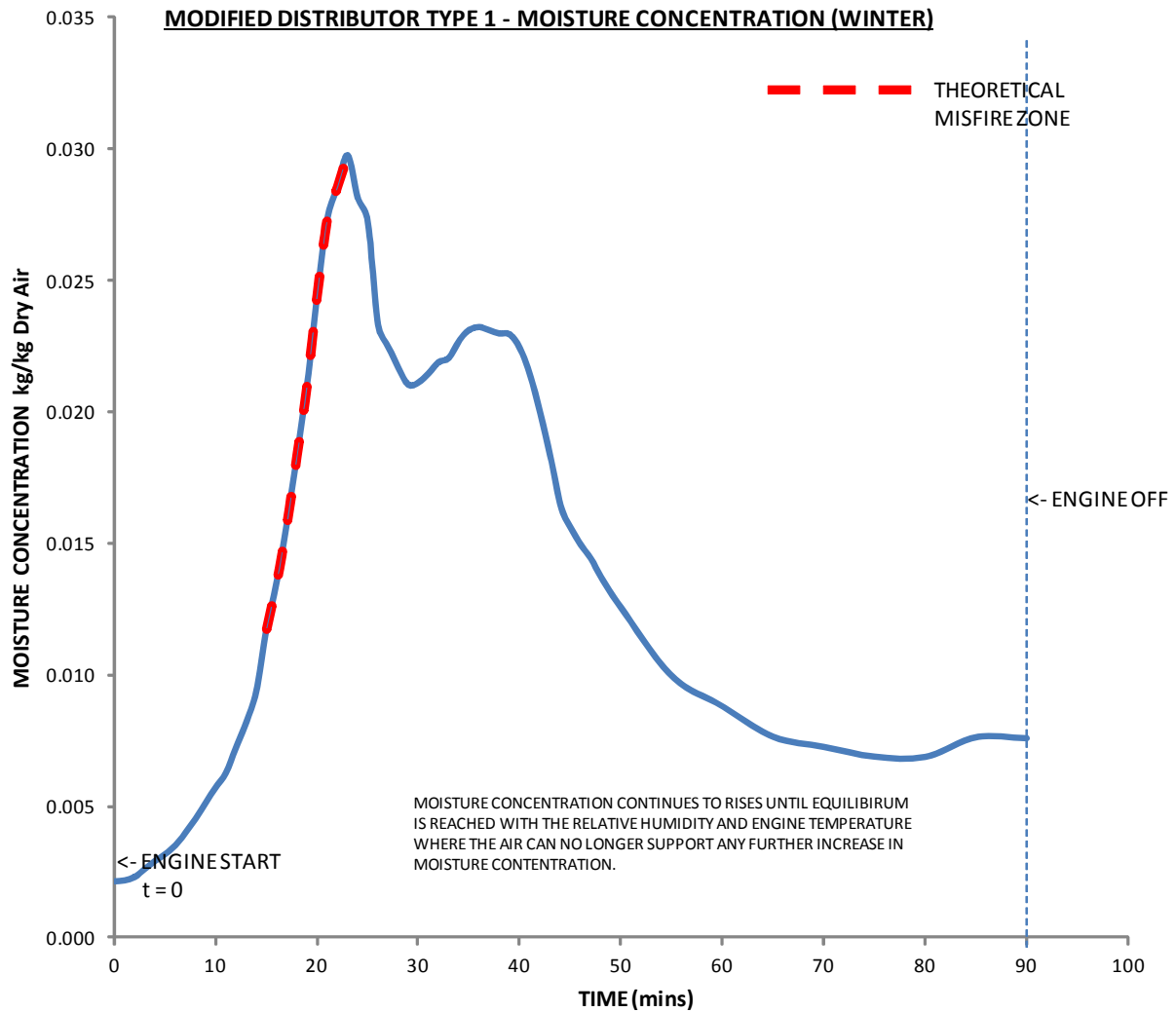


Figure 30 RUN #6 - 13 Feb 2018 - Graph of Moisture Concentration v's Time

A peak moisture concentration of 0.030 kg/kg dry air was reached at $t = 25$ minutes. The peak fell off to approximately 0.021 kg/kg dry air at $t = 30$ minutes, and then rose again to 0.023 kg/kg dry air at $t = 38$ minutes.

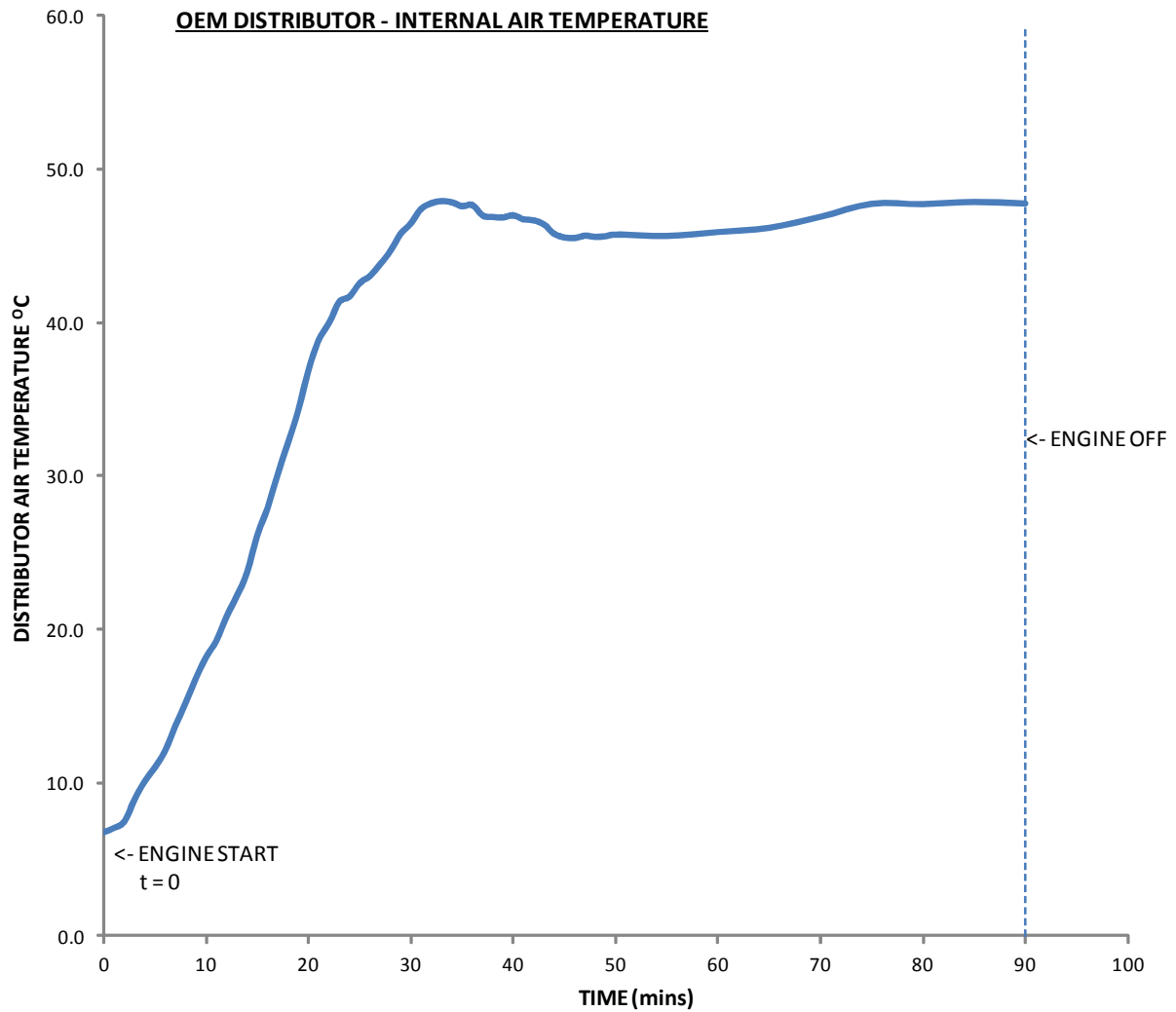


Figure 31 RUN #6 - 13 Feb 2018 - Graph of Distributor Air Temperature v's Time

The temperature of the air inside the distributor at t = 0 minutes at the point of engine start was 8 deg C.

The peak temperature of the air inside the distributor reached a plateau of 48 deg C at t = 32 minutes.

7) RUN #7 - 14 Feb 2018 - MODIFIED DISTRIBUTOR CAP TYPE 2 - NO MISFIRE

To examine Modification Type #2 - two rows of additional vents near the top of the cap.

RUN #7 - 2018-02-14 Garage RH = **45%** Ambient T = **7.0 deg C** Altitude = **52** m.a.s.l.
 Ambient RH = **70%**

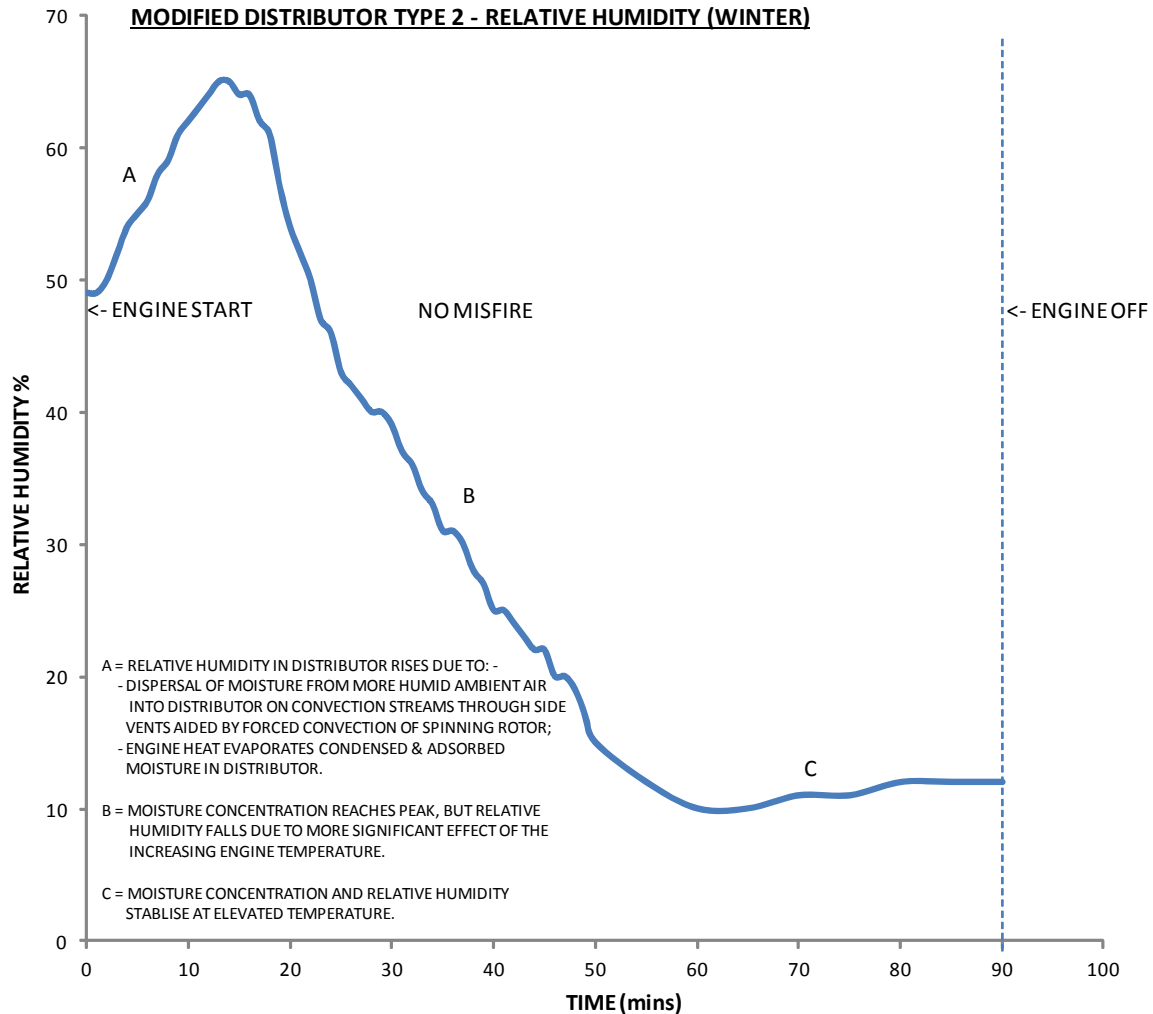


Figure 32 RUN #7 - 14 Feb 2018 - Graph of RH % v's Time

The drop in relative humidity starting at approximately $t = 15$ minutes might suggest the onset of some condensation inside the cap. However when we examine the graph of moisture concentration of the air against time on the next page, we can see that the moisture concentration is increasing. Essentially condensation dehumidifies the air, so a drop in moisture concentration is synonymous with condensation. Since there was no significant drop in moisture concentration of the air inside the distributor at $t = 15$ minutes, we can deduce from this that condensation did not occur.

If we refer to the data in the Appendix we can see that the calculated temperature of the air inside the distributor cap (T_A) is less than the calculated minimum dry bulb ($t_{bp \min}$) temperature required to initiate condensation. This also indicates that condensation did not occur and therefore there was no theoretical risk of misfire, which concurs with the output from the UEI ADL 7100 scope traces. No misfires were recorded.

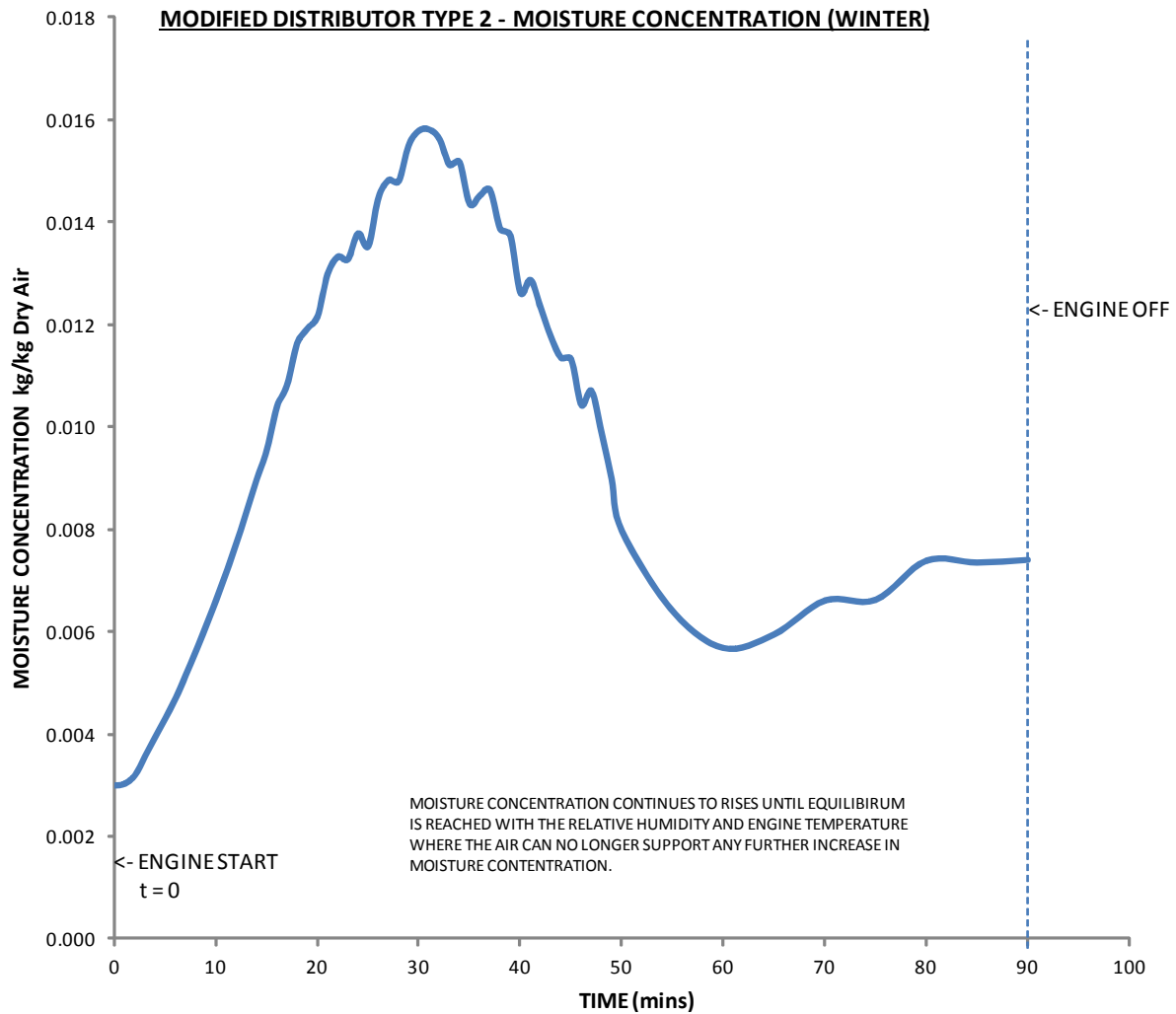


Figure 33 RUN #7 - 14 Feb 2018 - Graph of Moisture Concentration v's Time

A peak moisture concentration of 0.016 kg/kg dry air was reached at $t = 30$ minutes. The peak fell off to approximately 0.006 kg/kg dry air at $t = 60$ minutes, and then rose again to 0.007 kg/kg dry air at $t = 90$ minutes.

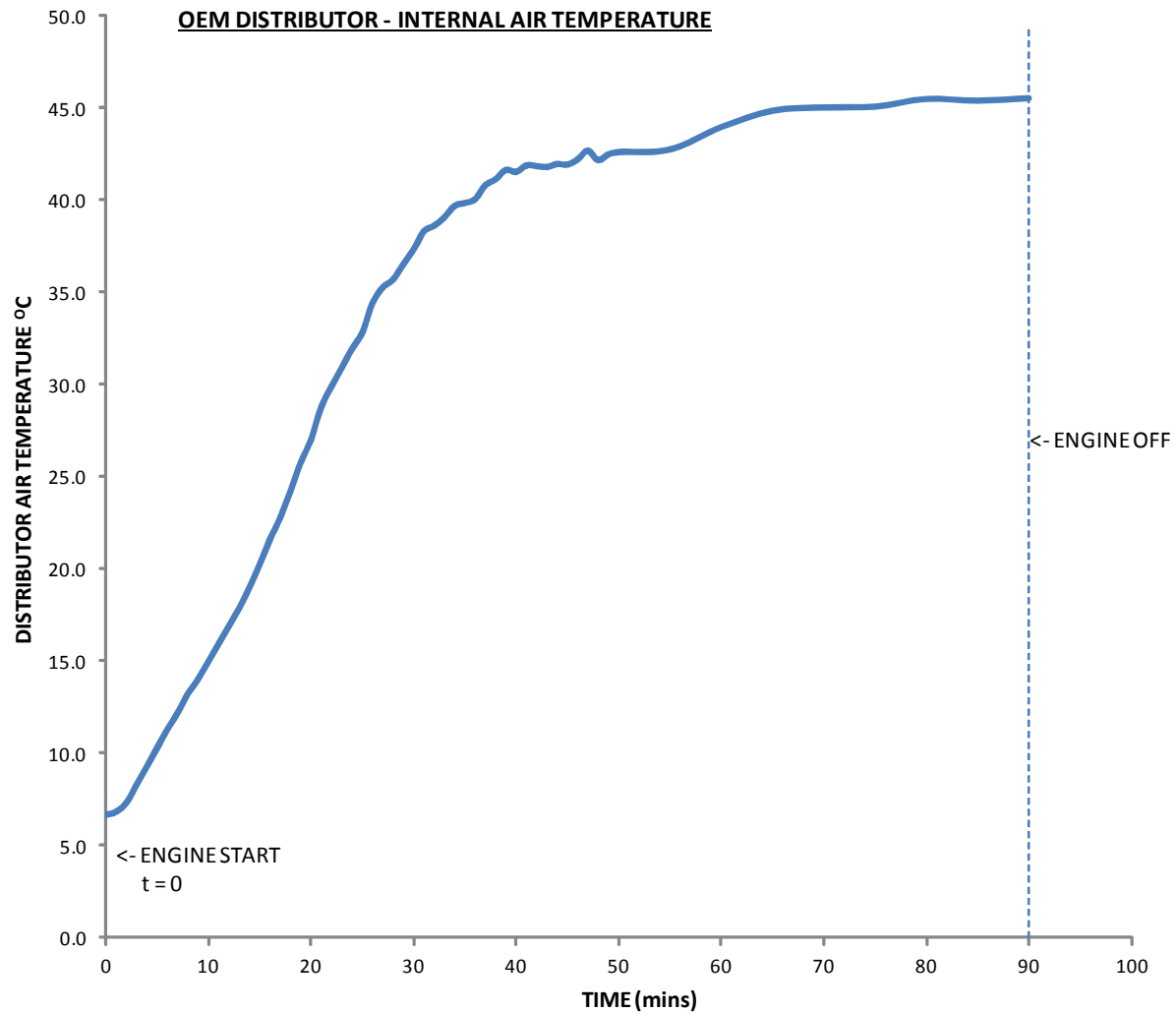


Figure 34 RUN #7 - 14 Feb 2018 - Graph of Distributor Air Temperature v's Time

The temperature of the air inside the distributor at t = 0 minutes at the point of engine start was 8 deg C.

The peak temperature of the air inside the distributor reached a plateau of 42 deg C at t = 50 minutes, rising slowly to 45 deg C at t = 90 minutes.

DISCUSSION

The movement of moisture in air is driven by the moisture gradient as well as the temperature gradient. A temperature gradient encourages the movement of water vapour by diffusion from an area of high temperature to low temperature. A moisture concentration gradient promotes a vapour drive from an area of high concentration to low concentration.

Psychrometric Chart for Air

Using the standard psychrometric (Mollier) chart, it can be shown that for a particular temperature gradient between the air inside the distributor and the distributor cap, a dew point can form at the surface of the distributor cap resulting in condensation inside the cap. Since the formation of a dew point is related to the temperature differential and partial and saturated vapour pressures, it is possible for a dew point, and hence condensation to form inside the distributor cap shortly after the engine has reached normal operating temperature.

Consequently this is why misfiring can occur shortly after the car is started in cold/damp/humid conditions, or if you park up and return to the car a short while later.

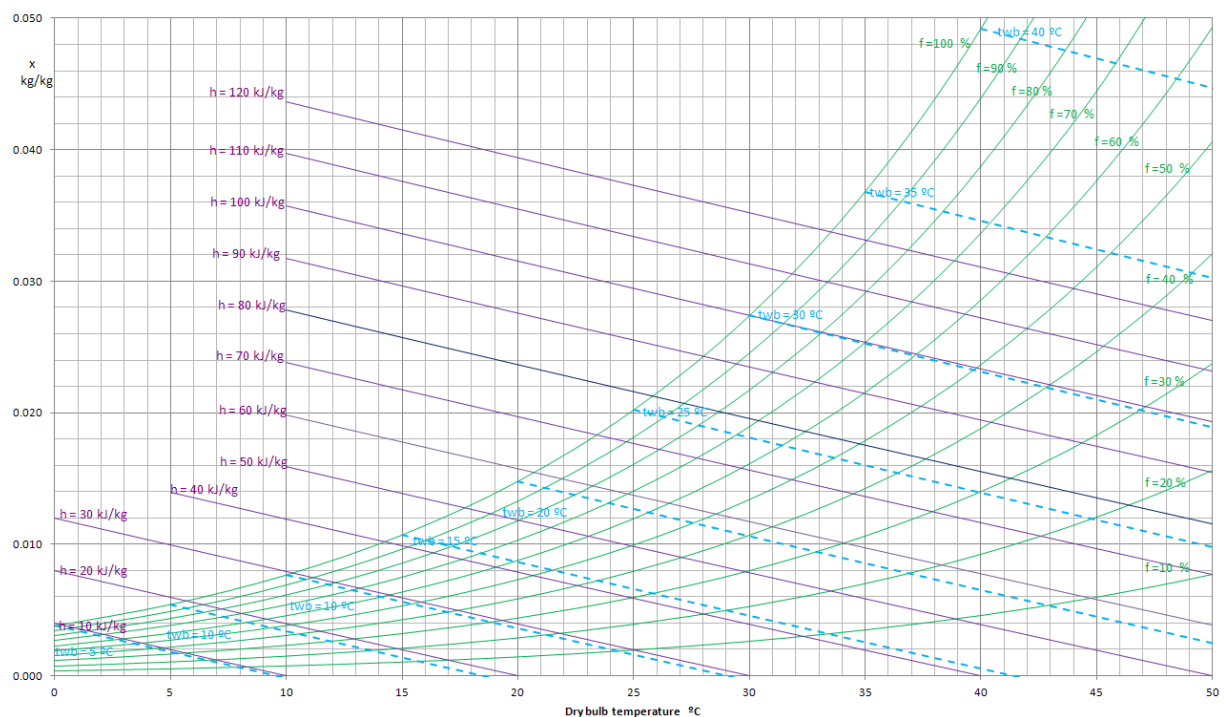


Figure 35 Psychrometric Chart for Altitude = 52m a.s.l.

In order to understand the mechanisms involved we will consider the interaction of the saturated vapour pressure, partial vapour pressure and temperature of the air inside the distributor cap, the ambient temperature and relative humidity, the temperatures of the alloy head and distributor cap, the relevant dew points and also the thermal conductivity of the alloy cylinder head and of the phenolic epoxy distributor cap.

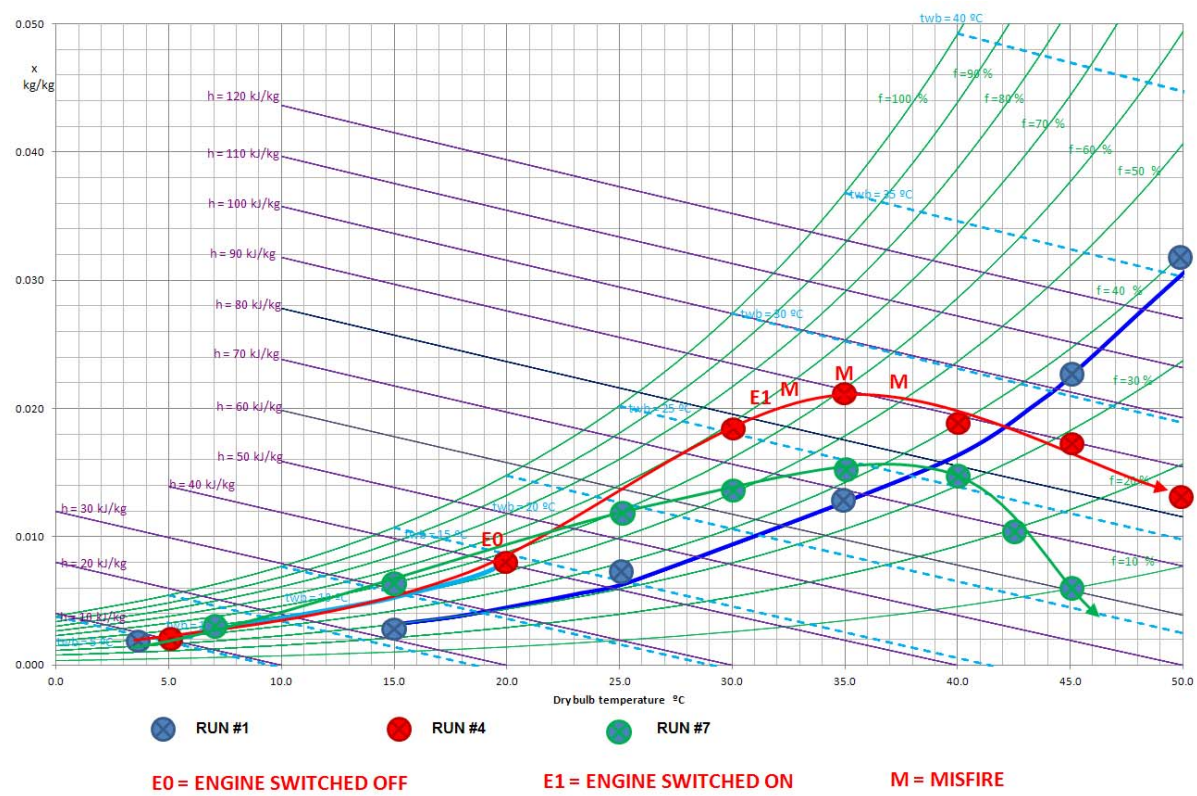


Figure 36 Psychrometric Chart for Runs #1, #4 and #7

Effects of Engine Cooling

When a hot engine is switched off, the alloy head will tend to cool more quickly than the air inside the distributor cap and the distributor cap itself. The property of a material that relates to how long the material can retain its heat over time is called the thermal inertia. The phenolic resin of the distributor cap has a low thermal conductivity and low thermal inertia and will tend to insulate and maintain the temperature of the air inside the cap for longer, while the alloy head cools more quickly due to the higher thermal conductivity and thermal inertia of alloy. This creates a temperature gradient, and any water vapour inside the distributor cap will tend to condense on the cooler surface of the alloy cylinder head when the temperature of the alloy head has fallen roughly 10 to 14 deg C below the temperature of the water vapour/air. Condensation occurs when the temperature of the air inside the distributor exceeds the minimum dry bulb air temperature required to initiate condensation. This latter requirement is dependent on the partial and saturated vapour pressures. The temperature at which condensation occurs is called the dew point temperature.

When condensation occurs, the relative humidity and moisture concentration of the air falls. By measuring this change (or trend) in relative humidity and moisture concentration, and looking for this trend, we can predict when a misfire is likely to occur. We can forecast when the misfire will typically occur by looking at the physical conditions inside the distributor cap that elicit this trend.

In practice, a misfire occurs when the following physical conditions occur instantaneously: -

- a) the temperature of the air inside the distributor exceeds the minimum dry bulb air temperature required to initiate condensation, which can be calculated using standard physics equations of enthalpy.
- b) the relative humidity of the air inside the cap falls due to the dehumidifying effect of condensation.
- c) the moisture concentration of the air inside the cap falls.

Typically, the synthetic or mineral fillers used in the manufacture of the phenolic epoxy resin insulating cup inside the distributor are hygroscopic and readily adsorb water vapour. Since the insulating cup and alloy head are in close proximity, this potentially results in the relative humidity of the air at these interfaces dropping further still. The combination of condensation and adsorption creates an imbalance in partial vapour pressures between the drier air adjacent the alloy head and insulating cup, and the more moist air adjacent the distributor cap.

As the engine cools down further over the period of several hours, there will be a water vapour drive by diffusion towards the relatively drier cooler air adjacent the inner surface of the cylinder head. The water vapour condenses on the surface of the cooler cylinder head; the relative humidity is depressed; and the cycle continues until vapour pressure equilibrium is reached several hours later.

Effects of High Ambient Relative Humidity and Engine Cooling

However, another significant mechanism may also occur. A mechanism that can redefine the misfire problem from that of a barely noticeable misfire to a complete failure of the ignition system.

In climatic, coastal or tropical areas of the world with relatively high levels of ambient relative humidity of typically 60% to 100%, a vapour drive can also occur between the ambient air and the relatively drier air inside the cap. In essence, as the moisture concentration of the air inside the distributor cap falls due to condensation and adsorption, more moisture vapour is drawn in to the distributor cap from the moisture laden ambient air outside by natural diffusion through the existing ventilation slots that allow ozone to escape the distributor cap during normal running conditions. Once inside the distributor cap the additional water vapour then condenses on the cooler surface of the alloy cylinder head, and the cycle continues until partial vapour pressure equilibrium is reached. Note that as soon as the concentration of water vapour inside the distributor cap reduces due to condensation, it is replenished by the migration of the ambient water vapour by diffusion.

Effects of Engine Warm Up

During the engine warm up phase the water vapour pressure inside the distributor cap initially climbs rapidly due to: -

- 1) evaporation of condensed water on the hot alloy head;
- 2) evaporation of adsorbed water from the warm insulator cup; and
- 3) emission of blow-by of humid crankcase gases via the camshaft oil seal. Note that this only occurs if the seals are both a) very worn and leaking oil into the distributor cap, and b) the crankcase breather system is compromised and not working efficiently.

While the engine is warming up there will be a vapour drive in the opposite direction from the warmer air adjacent the cylinder head to the relatively cooler drier air at the interface with the distributor cap. When the temperature of the air inside the distributor cap increases to roughly 10 to 14 deg C higher than the temperature of the cooler distributor cap, condensation will typically occur on the face of the distributor cap, providing that the temperature of the air inside the distributor exceeds the minimum dry bulb air temperature required to initiate condensation. This latter requirement is dependent on the partial and saturated vapour pressures. When condensation occurs, the relative humidity of the air at this interface falls rapidly.

Since water vapour is lighter than air, the water vapour tends to rise inside the distributor cap. Owing to the design of the OEM distributor caps, the only ventilation provided is at the bottom of the cap to allow ozone to escape, which is heavier than air. Unfortunately the existing vents are too low to allow the rising water vapour to escape, and the moisture vapour inevitably becomes trapped inside the distributor cap.

Effects of High Ambient Relative Humidity and Engine Warm Up

In climatic, coastal or tropical areas of the world with relatively high levels of ambient relative humidity of typically 60% to 100%, the additional water vapour that can be drawn into the distributor cap during the cooling phase occurs with every cycle of engine warming and cooling up to a point. Since the moisture vapour cannot escape and is effectively trapped inside the distributor cap, the moisture concentration of the air inside the distributor cap increases with every warming and cooling cycle up to the point where the saturated vapour pressure of the air inside the distributor cap is reached. This may take anywhere from 2 to 26 weeks on average. For this reason, the replacing or cleaning the distributor caps is only a temporary solution. Reoccurrence of the misfire will unfortunately be inevitable.

Relative Humidity and Temperature

In order to illustrate the relationship between relative humidity and temperature, we can look at the physical changes inside the cap when a new distributor cap is installed. As the engine reaches normal operating temperature, the temperature of air inside distributor will be reach approximately 50 deg C. To maintain equilibrium, the relative humidity of the warm air inside the distributor cap reduces to approximately 10%. In reality there would be a rise in relative humidity initially as the condensed and adsorbed water evaporates, but in this scenario we are assuming that the initial conditions are dry and there is no condensed or adsorbed water inside the distributor to start with.

Warm air can hold more moisture than cool air, so the warm air inside the distributor starts to draw in more moisture by diffusion through the vents in the side of the distributor cap, and the relative humidity starts to gradually rise again. The initial lowering of the relative humidity happens relatively quickly (20minutes) because it is temperature dependent. However the later gradual rise of the relative humidity is much slower (hours).

For instance, say at the start the ambient relative humidity is 35%, and the air temperature is 5 deg C. The moisture concentration of the ambient air would be approximately 1%. When the engine reaches operating temperature, the relative humidity inside cap will drop quickly (after approximately 60 minutes) to 10% to maintain equilibrium at the same moisture content of 1%, but at a higher temperature. After the engine is switched off the relative humidity will gradually start to rise again as moisture is drawn in through the vents in the distributor to bring the relative humidity back up to 35%. Because warm air can hold more moisture at a given relative humidity, the moisture concentration increases to a peak of approximately 5% by mass inside the distributor. As a comparison, the moisture concentration near the coast would be typically around 3.5% by mass.

Since water vapour is lighter than air, and there are no vents in the upper part of the cap, the moisture vapour is trapped inside the cap. When the engine cools the air inside the distributor can no longer hold moisture at this concentration and the moisture content gradually falls back to approximately 1% as condensation occurs. The difference in moisture concentration of 4% relates to the amount of condensation that occurs inside the distributor mainly on the surface of the recess in the alloy head during cooling.

When the engine is restarted again in similar ambient conditions, the condensed water starts to quickly evaporate as the engine temperature starts to rise. The rate of evaporation increases exponentially, quickly increasing the relative humidity of the air inside the cap from approximately 10% to 50%, and the moisture content from approximately 1% to 4%. Since the cap material is a polymer resin it has a lower thermal conductivity than the alloy head and the temperature rise of the cap lags behind the increase in temp rise of the alloy head and air inside the cap. The warmer moist air at the cooler surface of the cap starts to condense again, but this time the water vapour condenses on the inside of the distributor cap and misfiring occurs.

Condensation and Dehumidification

The main effect of the condensation is to dehumidify the air near the cap as moisture is removed from the air and condenses on the cap. This causes the relative humidity to fall off.

As the engine temperature continues to rise, the cap temperature rises also, and the conditions for condensation are no longer present. The condensed water evaporates, and the relative humidity inside the cap starts to rise again.

As the temperature increases further to approximately 40 deg C, the relative humidity tends to reach a second peak of approximately 50% and then starts to fall off. At this point the moisture concentration has typically stabilised at a peak of around 5% by mass, and the relative humidity falls gradually back to approximately 10% to maintain the vapour pressure equilibrium as the temperature of the air inside the cap still continues to rise up to approximately 50deg C.

After the engine is switched off, the air inside the cap gradually cools, and the relative humidity starts to gradually rise again. When the engine cools, the air inside the distributor can no longer hold moisture at this concentration, and the moisture content gradually falls back to approximately 1%. The difference in moisture concentration of 4% condenses inside the distributor.

Camshaft Seal, Crankcase Blow-by Gases and Gasoline Fraction

Knowledge of the blow-by gas in the crank case is a very important consideration during engine development phase when the crank case ventilation system is being tested and optimized.

Fuel and water typically account for 2% and 4% of the blow-by gas mass fraction respectively.

The R129 has a vented crankcase. Blow-by gases are re-circulated via crankcase breather back into air cleaner box and inlet manifold.

But, if the cam seals are worn to the point where oil leaks, how significant is this, and how much of the blow-by water vapour from the combustion cycle leaks through the seals into the distributors?

Blow-by increases as the engine rpm reduces, and is highest at idle due to the higher inertia giving a longer time for the leakage to occur across the piston oil control rings.

Typically blow-by is around 5cfm at idle, so the amount of fuel and water entering the crankcase would be 0.1cfm and 0.2cfm respectively. Crankcase pressures are controlled by a 20mm diameter breather which connects the valve cover to the air box.

The pressure differential required to sustain a flow of 5cfm through the 20mm breather is estimated to be roughly -0.012psi, which comprises approximately -0.008psi depression in the air box and 0.004psi crankcase pressure. But the crankcase pressures vary from 0.004psi to 0.01psi depending on the engine conditions (idle to full speed).

At idle the negative pressure in the air box draws the blow-by gases back into the combustion cycle, and the crankcase pressure is around 0.004psi. If the oil filler cap is opened, the flow through the breather reduces, the blow-by gases exit through the oil filler aperture, and the crankcase pressure rises slightly. Putting the cap back on causes the crankcase pressure to drop again.

At higher vehicle speed and rpm, RAM air creates more positive pressure in the induction system, the manifold induction pressure reduces, but the amount of blow-by also reduces, which accounts for the slightly increased crankcase pressure of approx 0.01psi until you lift off the accelerator.

On average the crankcase pressure is probably just slightly positive around 0.01psi.

There is no PCV valve. Baffle plates and an oil drain inside the top of the valve cover separate the oil before it can be drawn into the air box. The breather system on these Mercedes Benz engines is non-mechanical, simple, and therefore very reliable.

The crankcase pressure is more than adequately controlled by the breather, and is so low that it would not pose a significant problem for oil seals, unless the seals were worn and leaking oil.

If the cam seals are worn, you might expect some oil and crankcase pressure leakage. However new or correctly working seals will prevent crankcase gases from passing.



Figure 37 Camshaft Seal

Water vapour is a lighter gas than other gaseous components of air at the same temperature, so humid air will tend to rise by natural convection.

The gasoline fraction (2% by mass of the blow-by gases) is a heavier gas than the other gaseous components of air at the same temperature, so the gas fraction will tend to fall by natural convection.

The vents in the distributor caps are near the bottom, around 4 o'clock. So these would readily allow the heavier gasoline and ozone component to escape to the atmosphere, helped along by the mechanical convection of the spinning rotor, but the water vapour would be trapped in the top of the cap.

Additional Ventilation

Additional vents would ideally be positioned at the top of the cap to allow the water vapour inside the distributor cap to disperse before it can condense on the distributor cap and cause a misfire.

The additional vents have two purposes: -

- 1) To disperse moisture vapour from inside the cap.
- 2) To increase the effective volume of the air inside the distributor cap that is being heated. This helps to slow down the rate of increase in temperature of the air inside the distributor cap and therefore reduce the thermal difference between the air inside the distributor cap and the cap itself as the engine warms up. The thermal differential is one of the factors that elicits the formation of a dew point and condensation inside the distributor cap. So additional vents are an innovative way of controlling this.

Misfires typically occurred in the unmodified OEM distributor between 15 to 30 minutes running time, at a moisture concentration range of 0.025 to 0.030 kg/kg dry air. The peak moisture concentration was approximately 0.060 kg/kg dry air.

With the modified distributor type #1, which had one set of 6 additional vents, the average moisture concentration between 15 to 30 minutes running time was 0.020 kg/kg dry air. The peak moisture concentration was 0.030 kg/kg dry air. Misfires were recorded within this range.

With the modified distributor type #2, which had two sets of 6 additional vents, the average moisture concentration between 15 to 30 minutes running time was 0.010 kg/kg dry air. The peak moisture concentration was 0.016 kg/kg dry air. No misfires were recorded.

Distributor Cap Type	Av Moisture Concentration (%) inside Distributor	Misfire
OEM	3%	YES
Modification Type #1	2%	YES
Modification Type #2	1%	NO

Table 1 Average Moisture Content in Distributor Against Occurrence of Misfire

CONCLUSIONS

The results indicate that additional ventilation is the key to solving the misfire problem by encouraging the moisture vapour inside the cap to vent out before it can condense inside the cap and reducing the temperature differential between the air inside the distributor, and the distributor cap.

The OE distributor cap design incorporates 6 pre-cut slot vents at the bottom of the cap, which allow the ozone (created by the electronic arc) to escape. Ozone is heavier than 'air', so it readily escapes through the bottom vents. It is important to maintain these vents and not block them up, because ozone is highly oxidising and will quickly damage the cap. If you seal up the vents the build up of ozone could also adversely affect the high tension voltage required to create the spark, which could lead to damage of other components of the ignition system.

Since moisture is lighter than air, and there are no pre-cut vents in the top of the base of the cap, the moisture vapour is trapped inside the cap.

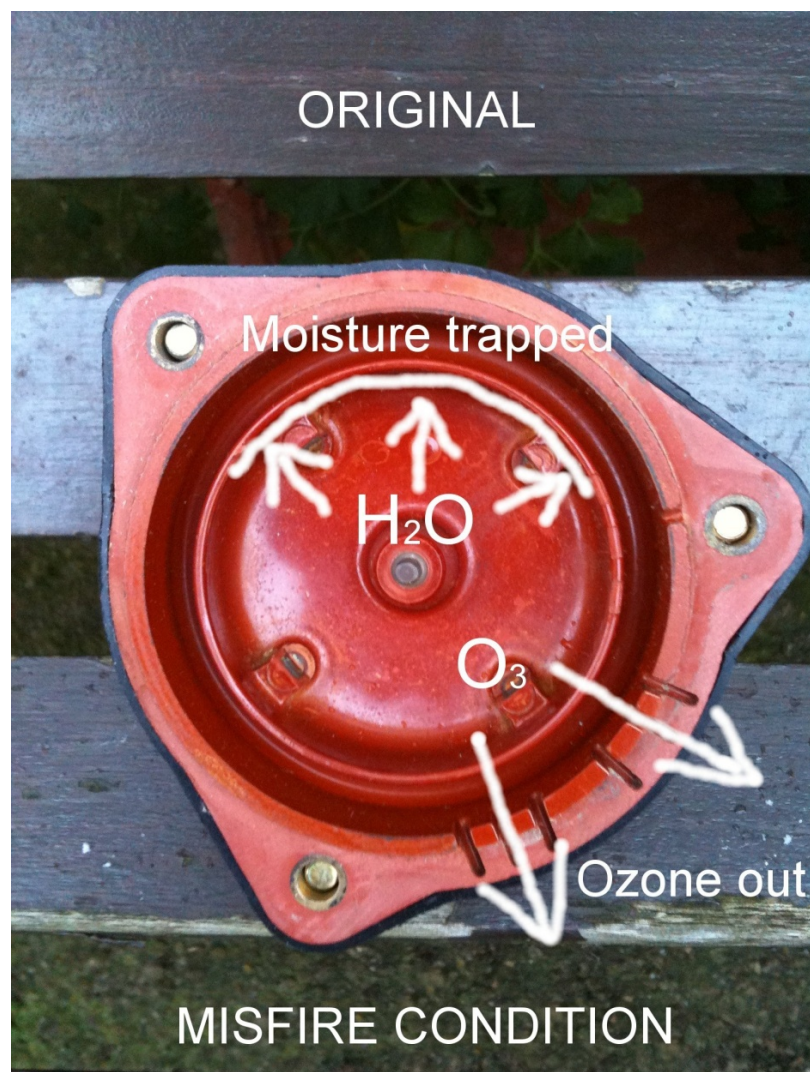


Figure 38 OEM Distributor Cap - Trapped Moisture

The Recommended Solution - Additional Vents - Modification Type #2

A relatively simple solution which I have road tested successfully for a period of 12 months involves cutting more slot vents in the caps as follows: -

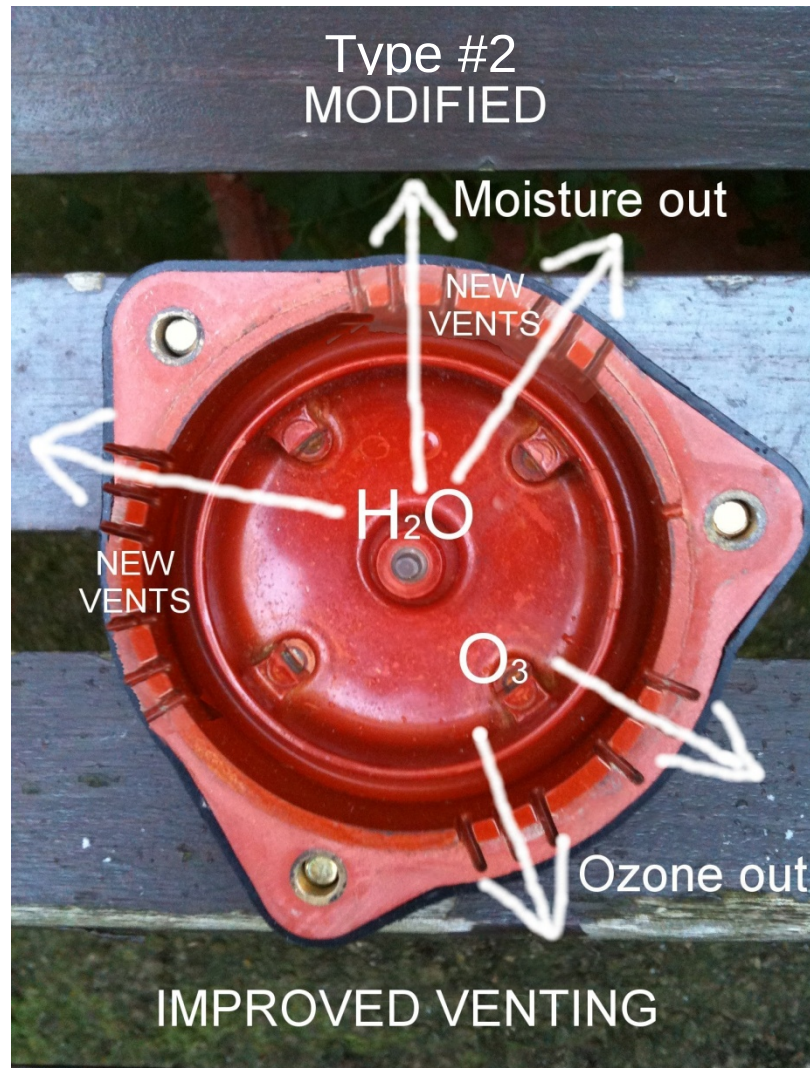


Figure 39 Modified Distributor Cap - Type 2 - Improved Venting

By doing this I recognised that I might invalidate any warranty left on the caps, but I decided that the potential benefits outweighed this consideration. I take no responsibility for any damage caused by anyone else attempting this modification, and please be careful when using cutting tools because of the risk of injury.

The only slight reservation I had with this approach was whether or not cutting additional vents would potentially make the distributors more susceptible to ingress of fluids or dust. The likelihood of the happening is very low, and the severity would also be low. So the overall risk is low and almost negligible in my view. The 12 month trial showed no signs of deleterious material in the distributor, so I can only conclude that benefits of additional vents appear to outweigh the risks.

Photo At 6 months During Road Test - 1500 Miles

The photo below depicts the inside of the distributor cap after 6 months and approximately 1500 miles.

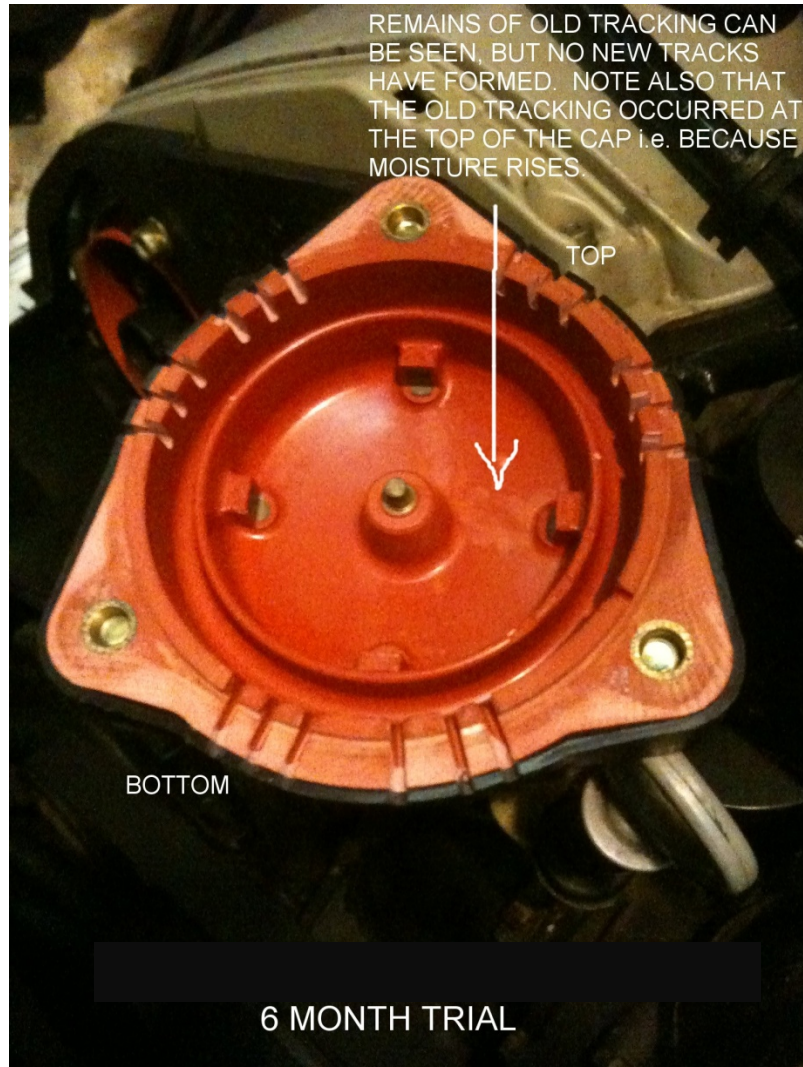


Figure 40 Modified Distributor Cap - Type 2 - At 6 months During Road Test - 1500 Miles

There is no evidence of any new carbon tracks having formed. There were some slight stains (arrow) due to the remains of cleaning away old tracks before I fitted to the car for the purposes of these tests. Bear in mind that these were old distributor caps. This is a photo of the cap at the moment it was removed from the cylinder head for inspection.

So far the results of the 6 month 1500 mile road test are positive and they align well with the predictions that we obtained using standard physics equations of enthalpy, the heat energy due to conduction through air, and the transfer of heat energy via convection through the various materials to the distributor cap.

The new vents were cut with a Dremel cutter in order to achieve a neat result.



Figure 41 Modified Distributor Cap - Type 2 - At 6 months During Road Test - 1500 Miles

Try to make sure, when cutting the additional vents, that the slots go deep enough. The above vents were cut approximately 1.5mm into the base of the distributor cap so that they also cut through into the black polypropylene cover. This ensures that the o-ring of the insulator cup does not hinder the diffusion of water vapour.

Photo at 12 months During Road Test - 3000 Miles

The photos below depicts the inside of the distributor cap after 12 months and approximately 3000 miles.

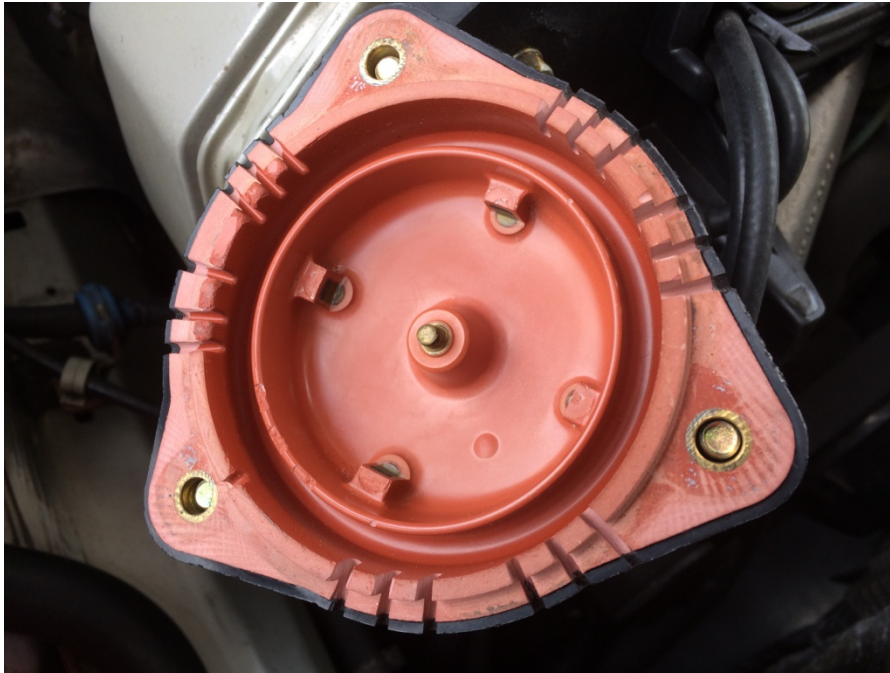


Figure 42 Modified Distributor Cap - Type 2 - At 12 months During Road Test - 3000 Miles

There is no evidence of any new carbon tracks having formed. This is a photo of the cap at the moment it was removed from the cylinder head for inspection. Very clean indeed.

So far the results of the 12 month 3000 mile road test are very positive and they align well with the theoretical predictions.



Figure 43 Modified Distributor Cap - Type 2 - At 12 months During Road Test - 3000 Miles

Permanent Cure or Band Aid?

Does the above solution just serve to minimise the risk of misfiring or is it a permanent cure? Well, we must be careful not to jump to conclusions, which is why it has been trialled for 12 months first. Given that the recommended modification has performed without fail for 12 months, it would be reasonable to conclude that it is potentially a permanent cure.

Other Benefits / Considerations

Typically distributor caps are changed on average every 2 years in the UK, and every 5 years in USA.

The full life expectancy of a distributor cap is seldom realised unless you happen to reside in an arid location where the ambient relative humidity rarely exceeds 25%, in which case you might expect to achieve a life expectancy of around 100k miles. In more humid climates the most common reason for changing the distributor caps is typically to cure a running problem such as a misfiring engine.

A potential benefit of the additional vents for those who reside in climatic, coastal or humid environments is the increase in the life of your distributor caps.

Moreover, if you have an old set of caps lying around in your garage and you were considering binning them, think again. These could potentially be cleaned up, modified and reused for a long while.

Alternative Interventions

Silicone / High Temperature Grease

The benefits of silicone grease are: it is a dielectric and water repellent. Silicone grease does not swell or soften rubber, which can be a problem with hydrocarbon based greases/dispersants.

Silicon grease is typically used on spark plug boots. It is generally not recommended to use silicone grease inside a distributor cap because it can interfere with the conduction between the HT poles.

I recently tested an alternative modification in 2016 that involved placing silicone grease between the insulator cup and alloy recess in the cylinder head. It was being purported by some members of the MercedesClub.Org forum in the UK in 2015 as a successful cure to engine misfiring. The distributor caps, rotors, brackets and insulator cups have to be removed in order to apply the silicone grease to the alloy recesses, and then the insulator cups, brackets, rotors and distributor caps are refitted. The rationale was evidently to try to use the dielectric, thermal insulation and water repellent properties of the silicone grease to inhibit arcing through the insulator, to provide a better thermal barrier between the distributor and alloy head, and to suppress the build-up of moisture between the insulator cup and cylinder head. Various members of the MercedesClub.Org forum (UK) have claimed positive results.

Silicone dielectric grease has good thermal stability up to around 200°C. It is a water repelling, non-melting, and lubricating dielectric grease that provides superior corrosion and arcing resistance for connectors. It is safe for most metals, rubbers, plastics and elastomers. It is resilient to extreme cold, heat, humidity, and exposure to high voltages.

Voltage arcing can be prevented due to its excellent dielectric properties, so I do not recommend that you smear dielectric silicone grease on the rotor or HT poles, otherwise accelerated burn out of the distributor poles/terminals could occur, and also damage to the coil(s) or ignition module due to higher HT voltages required to overcome the additional impedance caused by the silicone grease.

The thermal conductivity of silicone dielectric grease is around 0.16 W/(m.K). In comparison, aluminium is roughly 237 W/(m.K), water is 0.6 W/(m.K), air is 0.026 W/(m.K), and phenolic resin (used to make the distributor cap and insulator cup) is 0.15 W/(m.K). The thermal conductivity of the silicone grease is similar to phenolic resin of the distributor cup, but significantly less than air.

The silicone grease effectively fills the air gap between the insulator cup and alloy recess, therefore sealing the alloy recess from the air inside the distributor. The benefits of this are that this would theoretically delay the onset of condensation at the alloy recess when the engine is cooling down by moving the interface of the dew point from the cooler surface of the alloy to the slightly warmer face of the resin insulator cup. Any delay to the onset of condensation at the distributor cap by suppressing the temperature gradient across the distributor would probably be marginal. Overall, the silicone grease would probably help to suppress the build up of moisture in the distributor over time, to a degree.

The thermal insulating properties of the silicone grease are obviously not a prime factor, because the grease cannot be applied in sufficient thickness to significantly attenuate the heat flow, as illustrated in the following simple calculations:

Consider the heat flux, q :

$$q = -K \frac{dT}{dx}$$

where

q - heat flux vector $W m^{-2}$

T - temperature $^{\circ}K$

K - thermal conductivity $W m^{-1} ^{\circ}K^{-1}$

and also consider the divergence of heat flux:

$$\nabla \cdot q = \frac{dQ}{dt} = Q(x, t)/\rho c$$

divergence of heat flux - change in temperature with time = internal heat generation

where

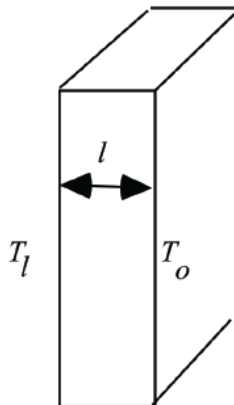
$Q()$ - heat generation $W m^{-3}$

c - heat capacity $J kg^{-1} ^{\circ}K^{-1}$ (energy needed to heat 1 kg by $1^{\circ}K$)

ρ - density $kg m^{-3}$

$\Gamma = K/\rho c$ thermal diffusivity $m^2 s^{-1}$

We can look at a simplified idealised model of the heat flow through the silicone grease and insulator cup as follows:



If we consider an isothermal block at a temperature of T_o . If we increase the temperature on the left side to T_l . After approximately τ seconds, the heat will reach the right side of the block.

$$\tau = l^2/\Gamma$$

The relevant properties of the insulator cup are:

insulator cup thickness	s1 =	2.5	mm
insulator cup thermal conductivity	k1 =	0.15	W/(m.K)
insulator cup thermal specific heat capacity	C1 =	1250	J/(kg.K)
insulator cup density	p1 =	1250	J/(kg.K)

Calculating the time that the heat takes to travel through the insulator cup, τ

$$\tau = l_1^2 / (k_1 / p_1 \cdot c_1)$$

$$\tau = 1.1 \text{ minutes}$$

It would take 1.1 minutes for the heat from the hot alloy surface to travel through the resin insulator cup.

If we consider the properties of the silicone grease (1mm thick):

silicone grease thickness	s2 =	1.0	mm
silicone grease thermal conductivity	k2 =	0.16	W/(m.K)
silicone grease thermal specific heat capacity	C2 =	1600	J/(kg.K)
silicone grease density	p2 =	989	kg/m ³

We can calculate the time that the heat takes to travel through the silicone grease and insulator cup:

$$\tau = (l_1 + l_2)^2 / ((l_1 \cdot k_1 / p_1 \cdot c_1) + (l_2 \cdot k_2 / p_2 \cdot c_2) / (l_1 + l_2))$$

$$\tau = 2.1 \text{ minutes}$$

It would take 2.1 minutes for the heat from the hot alloy surface to travel through the silicone grease and resin insulator cup.

In comparison, 2mm thick silicone grease would give a combined time of 3.4 minutes; 4mm thick 7.1 minutes and 8mm thick 18.4 minutes. It is not until we can achieve a thickness of 9mm that we would start to find that the thermal insulating property of silicone grease would delay the heat flow, and thus thermal gradient, sufficiently to prevent the formation of condensation at the distributor cap.

Because of the finite gap between the alloy surface and insulator cup, we can only expect to achieve a thickness of silicone grease of roughly 1 to 2mm. We can therefore conclude that the silicone grease does not significantly attenuate the flow of heat through the components of the distributor. With regard to the thermal insulating effect of the grease, there are no particular benefits.

The main effect of the silicone grease is to push the dew point interface a few millimetres from the cooler face of the alloy recess to the slightly warmer face of the insulator cup during engine cooling.

Since it only takes roughly 2 minutes for the temperature of the insulator cup to equalise to the temperature of the cooler alloy surface, the influence on the thermal gradient inside the distributor is marginal. Therefore the best that we could reasonably expect from this modification is a slight delay of a few minutes in the formation of condensation. Ultimately condensation will still occur inside the distributor under the right damp/humid ambient conditions.

The following test runs #8 and #9 use the raw test data from test run #4, which represented the worst case conditions for a misfire when the engine was run for a short while, then stopped and restarted a short while afterwards. The temperature of the air inside the distributor (TA) is calculated from the temperature of the insulator cup allowing for the increased thermal insulating effect of the silicone grease, using the above theory of thermal conductivity and diffusivity.

The results of #8 indicate that despite the silicone grease, condensation still potentially occurs inside the distributor and consequently there would still be a risk of misfire, as shown in the graphs below.

Test Run #8 - Silicone Grease Between Insulator Cup and Alloy Recess

Silicone dielectric grease applied between insulator cup and ally recess
RUN #8 - 2018-02-12 Garage RH = 40% Ambient T = 7.5 deg C Thickness of silicone = 1.0 mm
 Ambient RH = 65% Altitude = 52 m.a.s.l Time delay = 2.1 mins

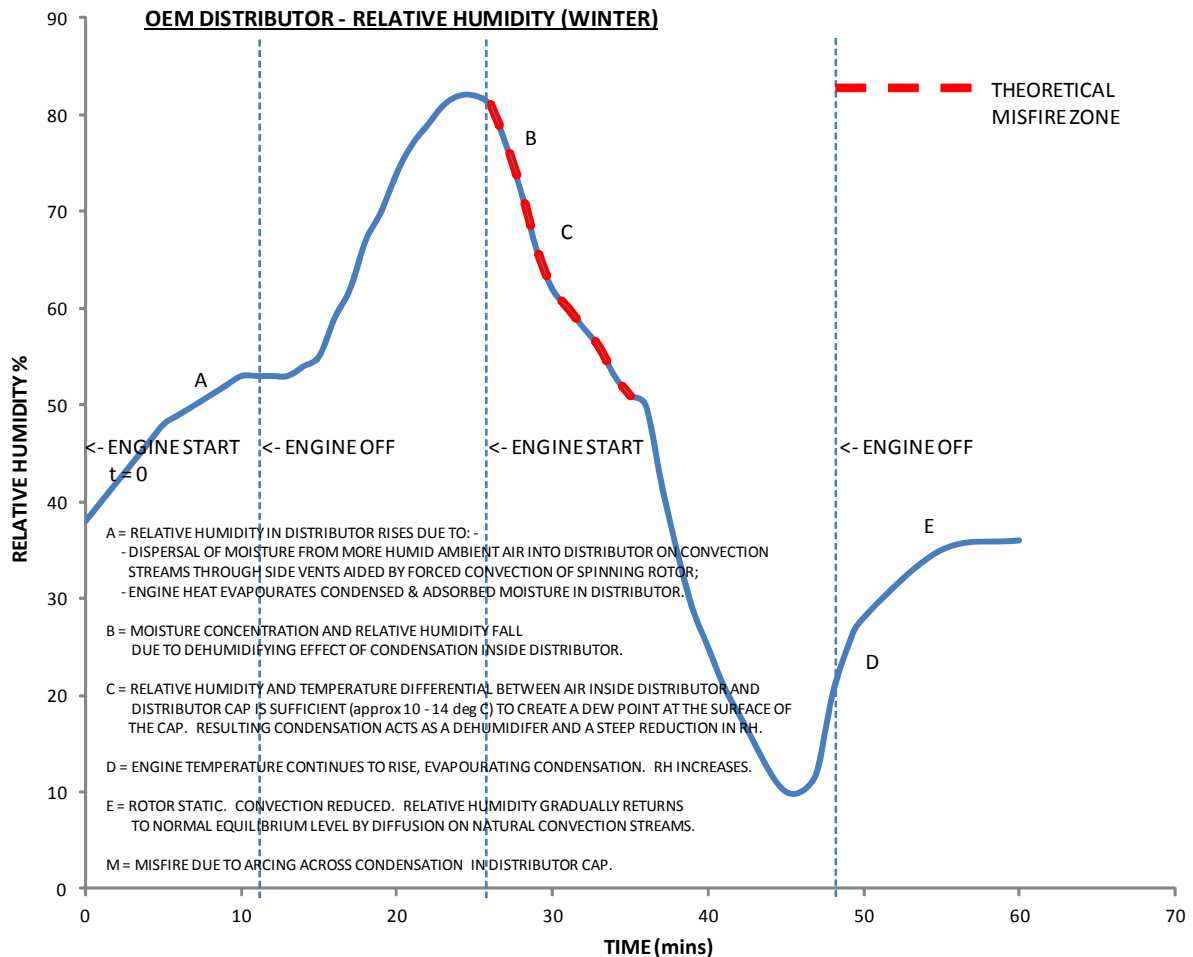


Figure 44 RUN #8 - Graph of RH % v's Time

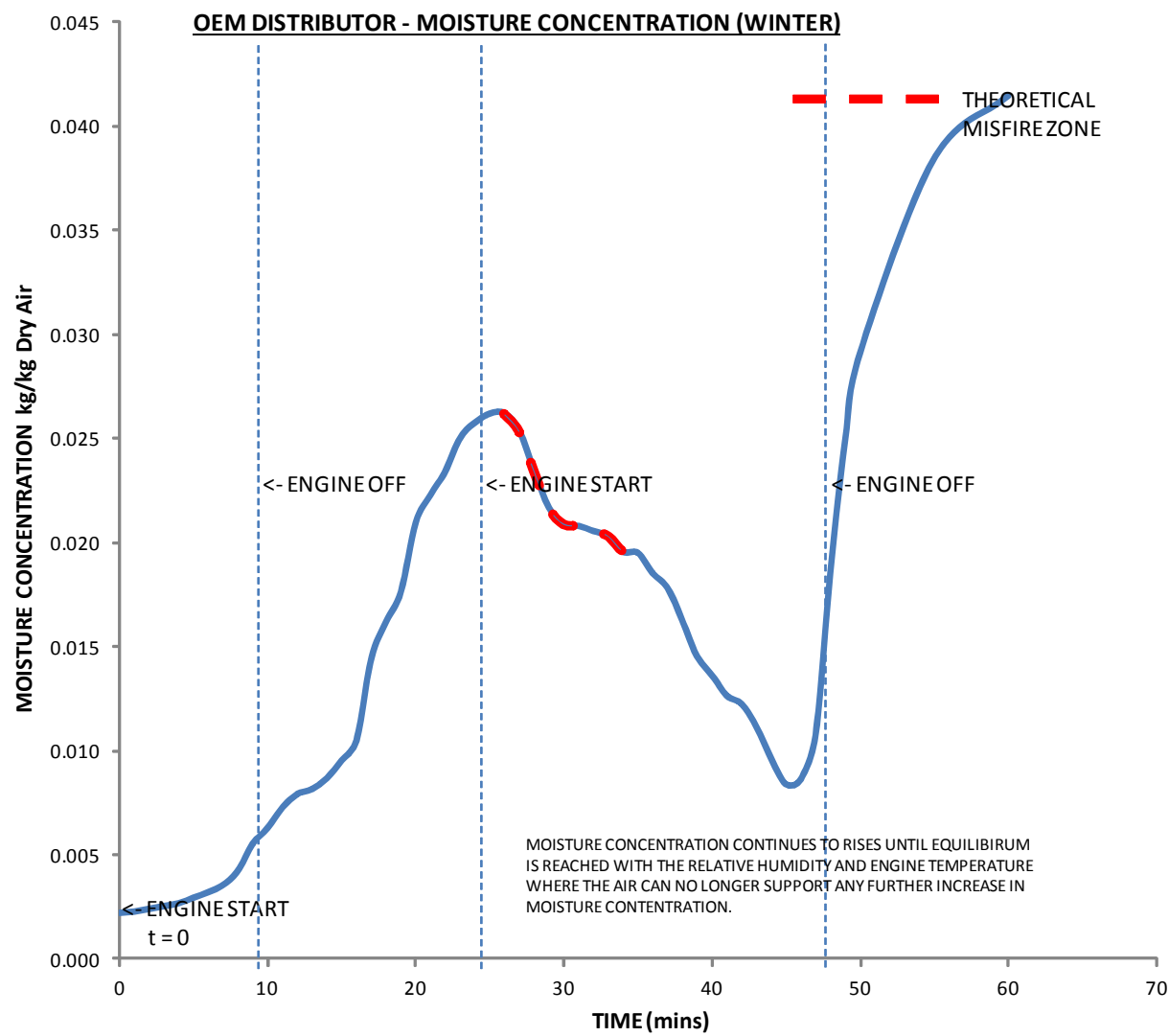


Figure 45 RUN #8 - Graph of Moisture Concentration v's Time

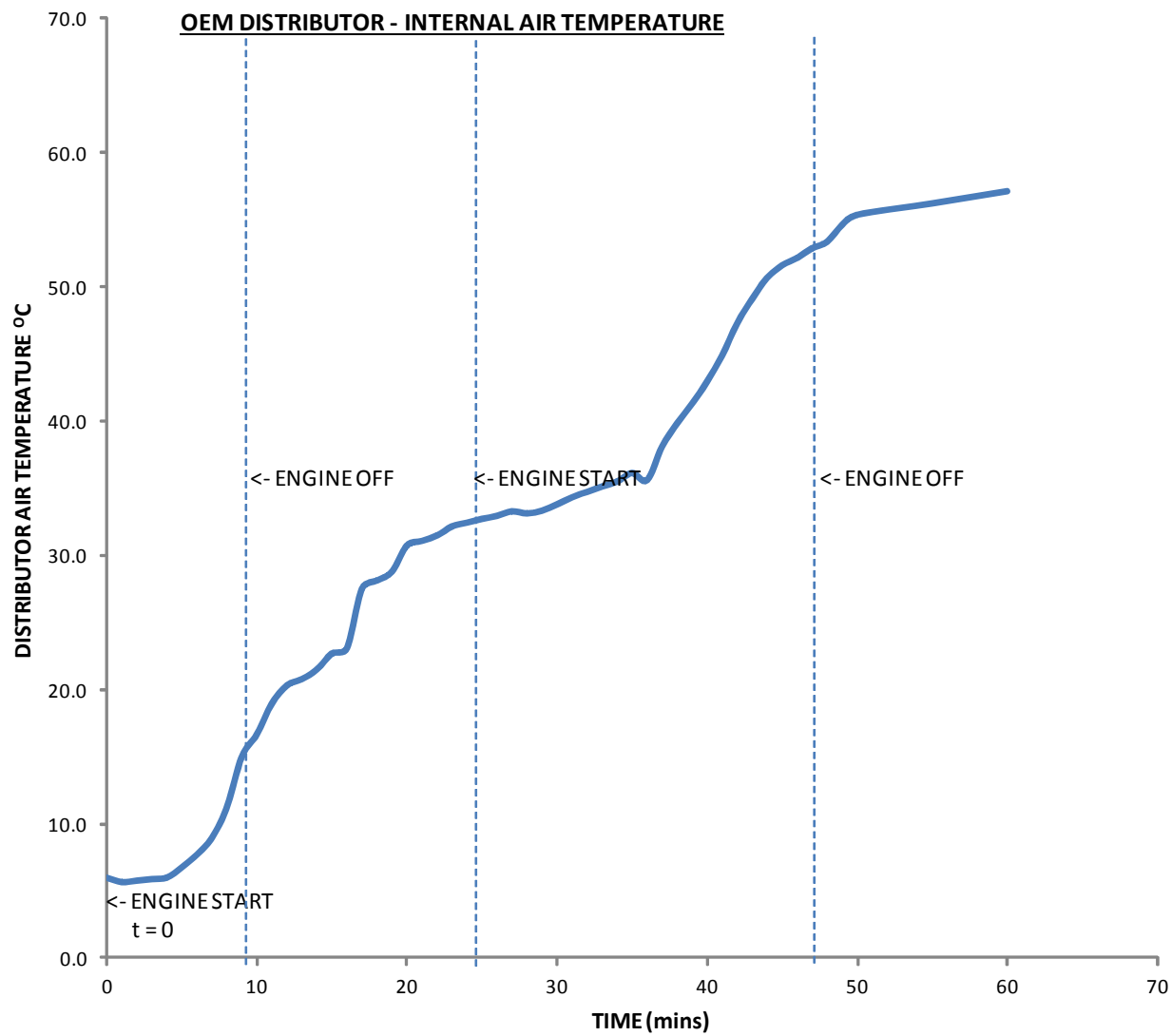


Figure 46 RUN #8 - Graph of Distributor Air Temperature v's Time

Test Run #9 - Silicone Grease Between Insulator Cup and Alloy Recess

Test run#9 is an iterative test to ascertain how much grease would theoretically be required to inhibit condensation sufficiently to prevent the misfire occurring entirely under run#4 ambient conditions.

The results indicate that the grease would have to be 9mm thick, which is obviously impractical.

Silicone dielectric grease applied between insulator cup and ally recess
RUN #8 - 2018-02-12 Garage RH = 40% Ambient T = 7.5 deg C Thickness of silicone = 9.0 mm
 Ambient RH = 65% Altitude = 52 m.a.s.l Time delay = 22.0 mins

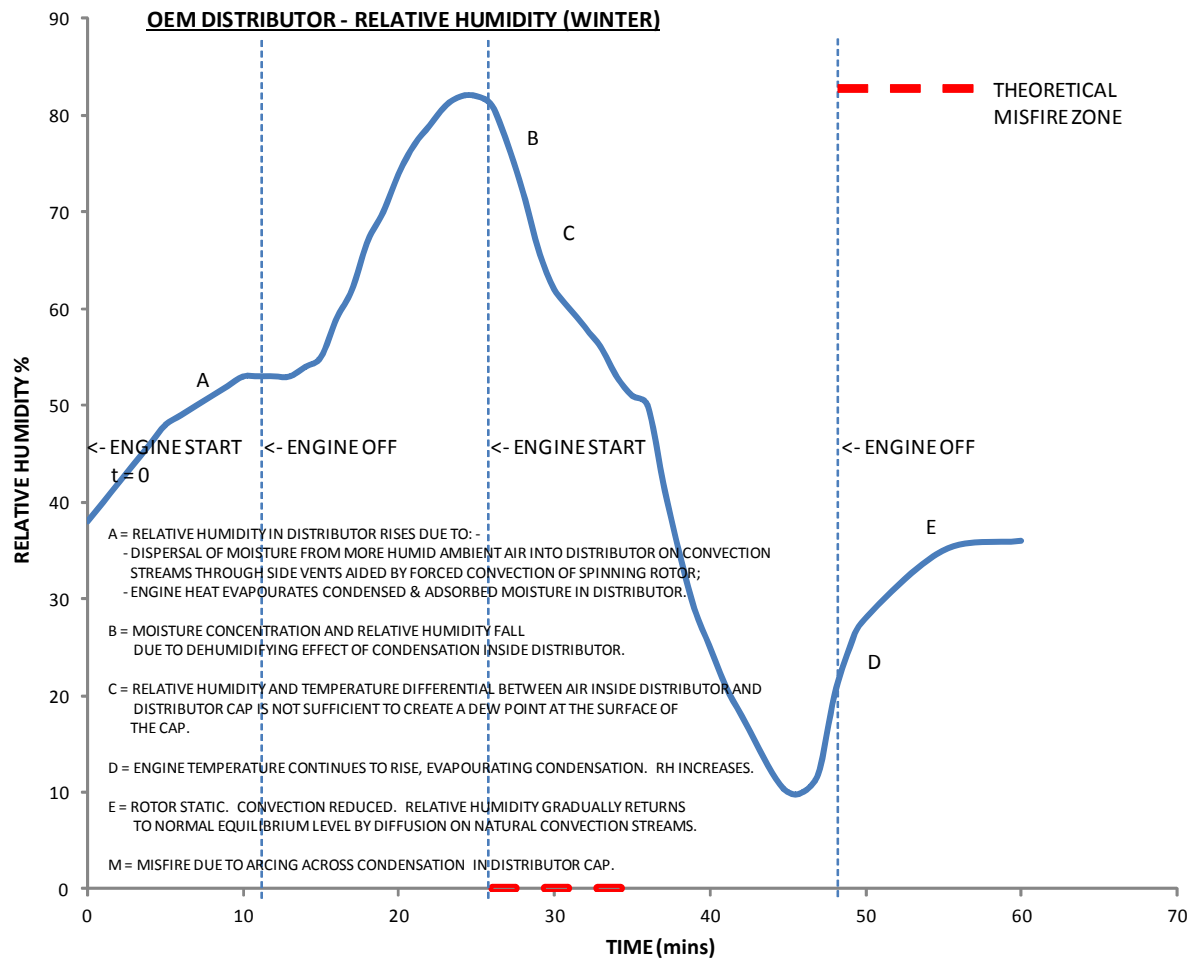


Figure 47 RUN #9 - Graph of RH % v's Time

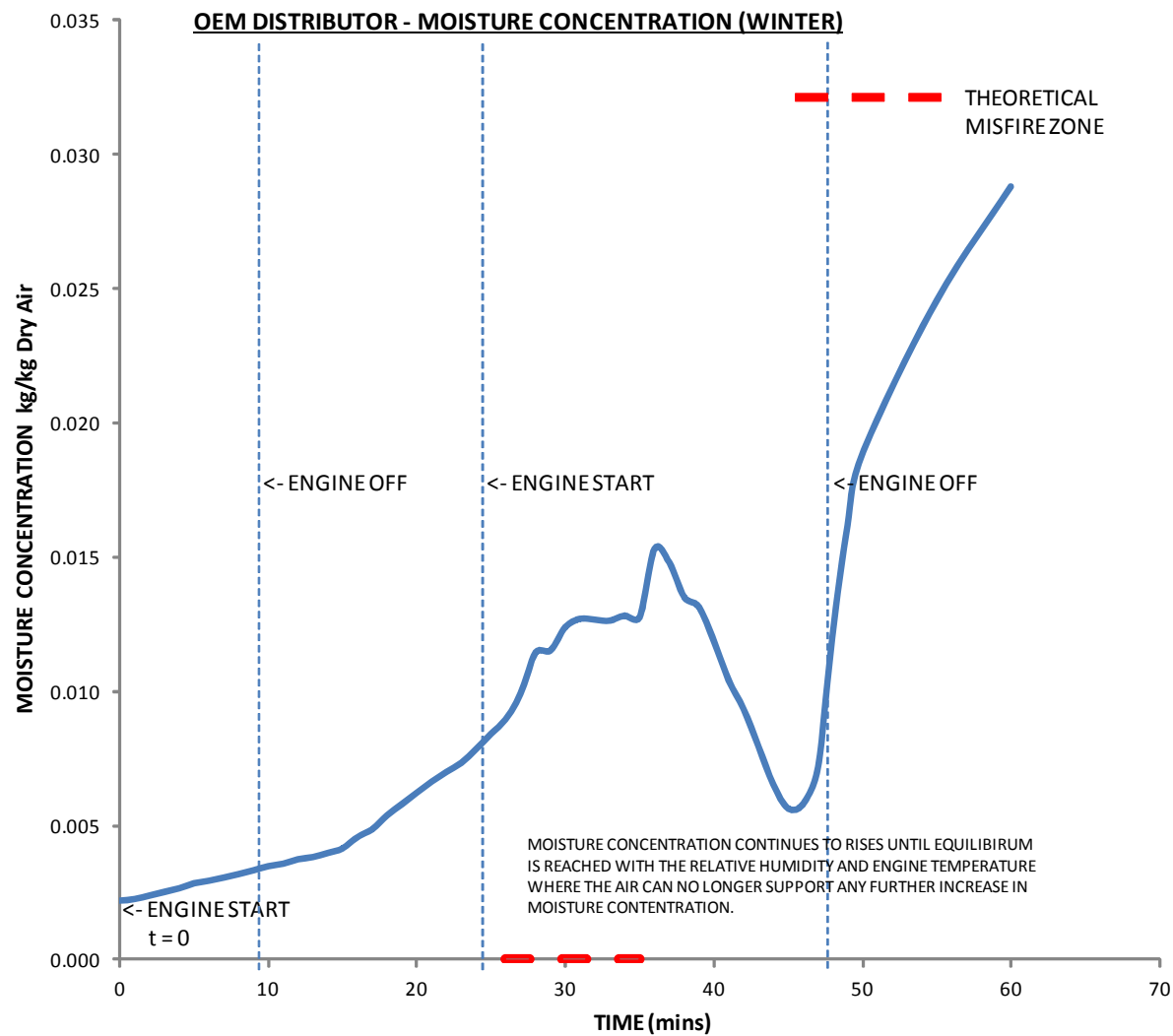
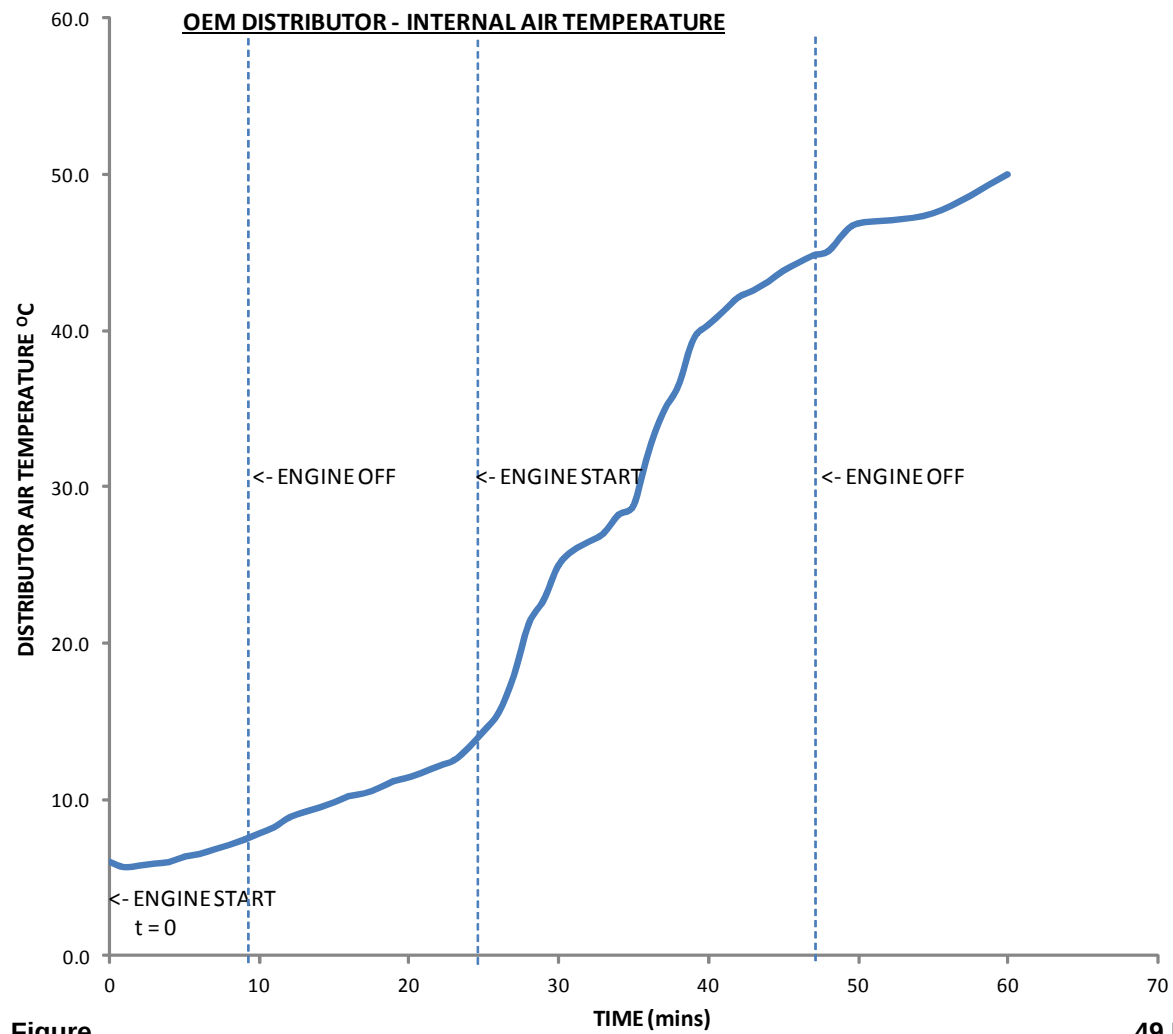


Figure 48 RUN #9 - Graph of Moisture Concentration v's Time



Figure

Graph of Distributor Air Temperature v's Time

49 RUN #9 -

The silicone grease does provide a more uniform thermal bridge between the alloy and insulator cup, but there are no significant benefits from this.

The grease would repel moisture from the face of the alloy recess, therefore ensuring that moisture cannot condense against the alloy recess. The moisture would condense on the inner face of the insulator cup instead, potentially increasing the risk of corrosion of the poles when the engine not used for a while, particularly when being laid up over winter.

To illustrate the fact that moisture vapour can still condense on the insulator cup, the photo of the insulator cup below shows condensation on cup. It was removed from the vehicle and photographed quickly to capture the moisture on the surface before it evaporated.



Figure 50 Condensation Reverse Side of Insulator Cup

The effectiveness of the silicone grease in suppressing the accumulation of water in the gap between alloy recess and the insulator cup largely depends on how much silicone grease is used, and this requires a bit of trial and error to get right. Too much, and the inside of the distributor could become contaminated with silicone grease, or the ozone vents could become blocked up, which are certainly not desirable outcomes.

Furthermore, the rate of evaporation of the silicone oil in silicone dielectric grease after 24 hours at 200°C is typically 2%. Silicone grease should really not be applied anywhere near the inside of an ignition distributor, particularly where there is a combination of heat and arcing. The silicone vapour given off when the silicone oil gets hot is converted to silicon carbide under arcing conditions, and the accumulation of the silicon carbide can cause the distributor HT poles to foul up. The knock on effect of this could be expensive because the HT voltages can increase as a result of the increased impedance at the poles due to fouling, risking failure of the coil(s) or ignition module.

Having tested the silicone grease method, I found that the early results looked promising because I was pleased to find that the misfire went away for a while. However a similar result could also be achieved by removing and cleaning the distributor caps, and the latter typically works for around 3 months before the misfiring returns.

With the silicone grease method, the misfire returned 9 months later, and on inspection I found that new carbon tracks had developed inside the distributor caps. This aligns with theoretical predictions.

The silicone grease method may be more effective in areas of low to moderate ambient relative humidity of around 40 to 75%, but the ambient relative humidity where I live is typically around 65 to 95% which is probably just sufficient to tip the balance and cause misfiring again with the silicone grease.

It would be preferable in my view to adopt a solution that does not involve introducing grease into the distributor, and one that actually prevents the build of moisture in the distributor in the first place, which I believe the additional vent method does.

I am also left with the question: If, without the silicone grease, water vapour is claimed to accumulate in the gap between the alloy recess and insulator cup, why are there no signs of corrosion of the alloy recess?



Figure 51 Photo of Alloy Recess (No Corrosion)

In conclusion, for those of us living in more humid areas (65% to 95%) I would recommend the additional air vent method first, and if this fails to work, you could try applying the silicone grease as a last resort in combination with the vents.

Other Considerations

While assessing the viability of the silicone grease method, we ought to also consider other misfire mechanisms and the effect that the silicone grease would potentially have on them.

For instance there is a misfire condition that is related to a gradual degradation of the insulator cups over time, which is discussed in more detail later on. As a result of a gradual adsorption of moisture over time, the HT arc finds a discrete path through the insulator to earth. This manifests itself as tell tale carbon traces in a circumferential pattern on the inside of the insulator cup.

The application of silicone grease behind the insulator cup would certainly have a beneficial effect in this case, and would probably eradicate misfires caused by this condition.

Therefore it is important to ascertain which misfire condition is present.

Unsuccessful Interventions

Modified Distributor Cap - Type 1

The report investigated the viability of two modifications.

The following modification comprised cutting only one additional set of vents instead of the recommended two. The results of the theoretical analysis indicated that condensation would still occur, and the testing confirmed that misfires still occurred.

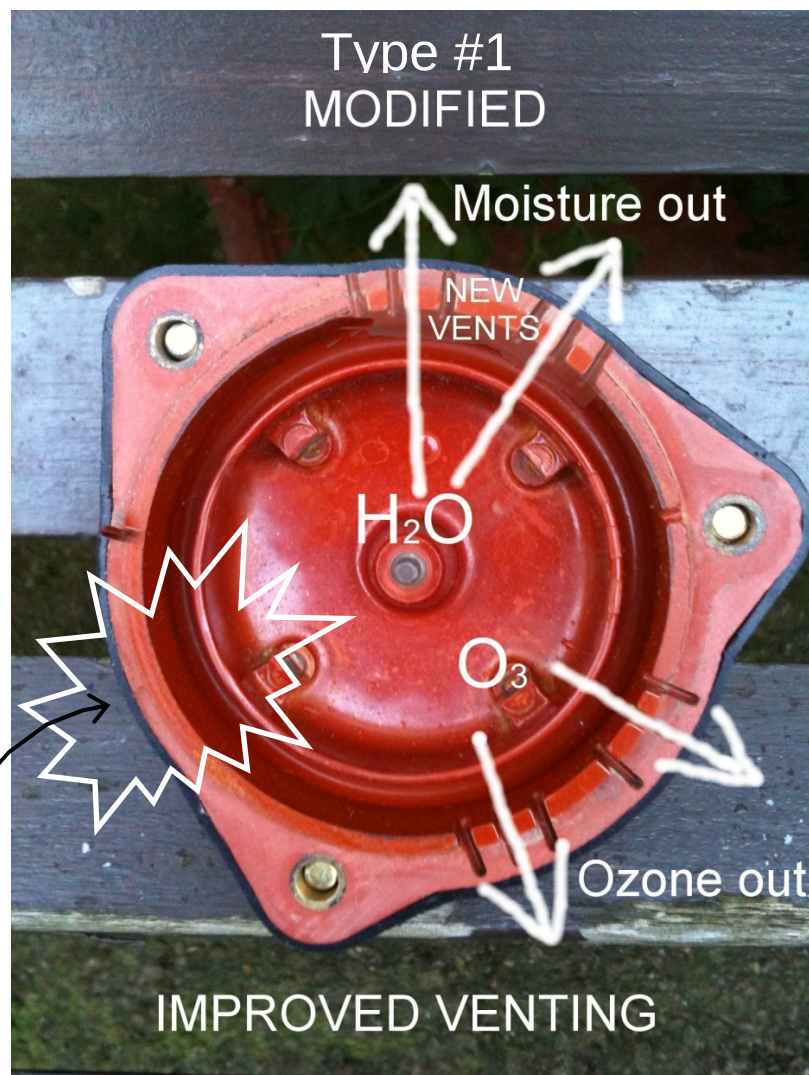


Figure 52 Modified Distributor Cap - Type 1 - One Set of Additional Vents

The reason why just one set of additional vents is not sufficient, despite the fact that the additional vents were placed at the most ideal position i.e. at the top of the cap, is because the additional vents have two purposes: -

1) To disperse moisture vapour from inside the cap.

2) To increase the effective volume of the air inside the distributor cap when it is being heated by the engine. This helps to slow down the rate of increase in temperature of the air inside the distributor cap and therefore reduce the thermal difference between the air inside the distributor cap and the cap itself as the engine warms up. The thermal differential is one of the factors that elicits the formation of a dew point and condensation inside the distributor cap. So additional vents are an innovative way of controlling this.

The 'half-way-house' modification of just one set of vents addressed criteria (1) above, but it did not adequately fulfil the requirements of (2).

Therefore I do not recommend just forming one set of additional vents. Always go for two sets if you can, as in the previous example, which clearly demonstrates the benefits of two sets of vents. To be clear, each set is 6 slots. Two sets means 12 additional slots. Given that there are 6 OEM vents already, the total (after modification) would be 18.

Water Displacement and Sealer Sprays

Water displacement sprays are often used to help diagnose moisture related ignition problems by spraying on the outside of the distributor caps and ignition leads, but they should be used sparingly and with caution, and should not be considered to be a remedial solution in their own right.

The light oil fractions in the spray are flammable, and they leave a residue. Over time the spray is readily absorbed by rubber and plastics, causing softening and degradation. High engine temperatures reduce the life-span/effectiveness of these products. If sprayed inside the cap, which I recommend that you don't, they do not remove the root cause, which is the water moisture, and this will remain in the distributor. Water displacement or sealer sprays do not prevent moisture build up inside distributors that arise from the natural moisture vapour in ambient air.

Is the use of water displacement and sealer sprays a reliable solution? No.

The Insulator Cup

The insulator cups are very expensive for what they are, and in my experience this suggests that Mercedes-Benz did not anticipate these would be normal service parts, which is probably reflected in the very high unit price. They do not need to be changed UNLESS there is obvious carbon tracking, or the cup has been affected by heat and moisture. The way to check is by the colour. The cups start out a red colour. When moisture is adsorbed into the molecular structure of the cup the cups gradually change colour from red to pink to orange to yellow. Although I have seen dark brown coloured versions, but not on R129s.



Figure 53 Insulator Cup



If the insulator cups are yellow, as in this image, I would consider replacing them because carbon tracks can start to form in the cups due to the adsorbed moisture, allowing the high tension spark to earth through the insulator.

Figure 54 Yellow Insulator Cup

To illustrate that the materials used in the construction of the insulator cups are potentially hygroscopic and could readily adsorb water molecules onto their structure, the photo below shows two insulator cups.

Hygroscopic resins are made up of long chain polar molecules that have a strong affinity to moisture and can adsorb water into their molecular structure if exposed to moisture. Some hygroscopic resins can store up to 10% of their weight in water.

The insulator cup on the left is brand new. The one on the right was also brand new, but it was immersed in cold water for 12 hours.

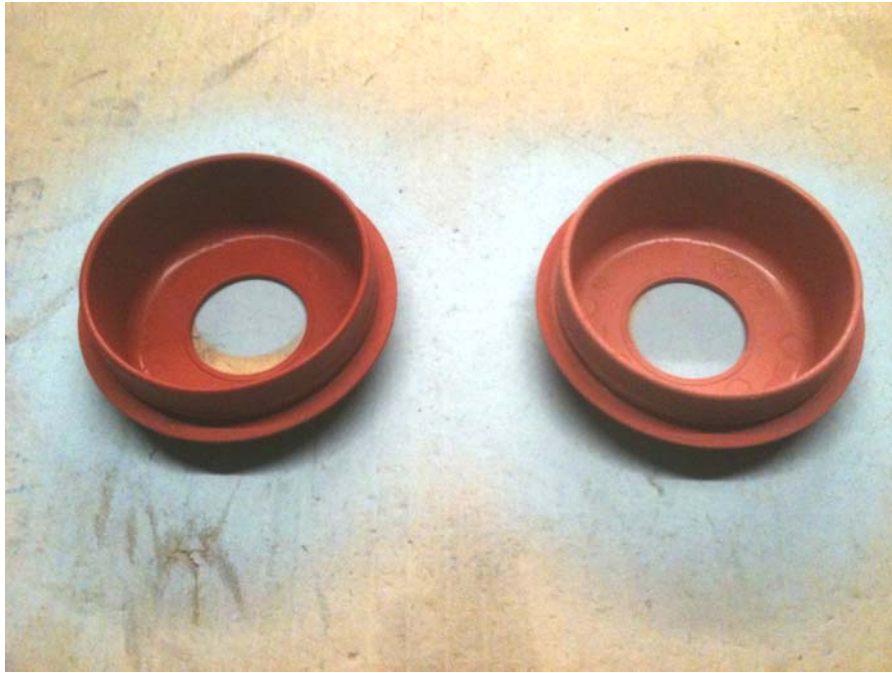


Figure 55 Hygroscopic Insulator Cup

The cup that was immersed in water (right) has changed colour because the water molecules have altered the molecular structure of the resin by a process of adsorption. As opposed to absorption, which is usually reversible, adsorption means that the water molecules form electrostatic bonds to the surface long chain resin molecules of the insulator cup and reversal is difficult because it requires both heat energy, dry convection and dispersal. Sure we have heat from the engine in the unmodified caps, but I am certainly not convinced that there is sufficient dry convection and dispersal in the OEM design.

Over time, the continual cycle of exposure to condensation and moist air without adequate dry convection and dispersal, which typically occurs inside unmodified distributor caps, can gradually cause the water adsorption to go deeper into the surface of the cup. This effect, along with the degradation due to heat, causes the colour of the cup to change and potentially compromises the insulating properties of the cup. A circumferential pattern of carbon tracks can form as a result due to high tension voltages passing through the conductive parts of the cup that have been compromised by heat and adsorbed moisture.

I have come across theories expressed by others that suggest that the cups are compromised by small cracks, and should be replaced because of this. I have not come across this, but I can see that small cracks could potentially draw moisture in due to capillary action, and thus could potentially elicit the same grounding effect of the HT voltage.

However, I would think that if cracks were likely to develop, they would be more likely to form in a radial pattern from a free edge i.e. from a crack propagator. I doubt that they would be perfectly circumferential, so I am not convinced by this argument. The opinions expressed in this section regarding the cups are just my views, based on simple tests, logic, theory and experience. I have not wrung the rag dry on the technical arguments over these cups, and probably I do not intend to.

I conclude that the recommended modifications to the distributor caps should promote ventilation and dispersal of moisture vapour and help prevent it from building up inside the distributor. This would certainly be beneficial also in promoting the structural integrity and longevity of the insulator cups.

Insulation Cup O-Ring

Within the distributor cap there is an o-ring seal attached to the insulating cup. The insulating cup is designed to prevent the distributor from shorting to ground, and promotes a compact distributor design.



Figure 56 Insulator Cup O-Ring

The o-ring has elastic characteristics that accommodate the thermal expansion and contraction of the cup, while ensuring that the cup remains seated and does not rattle about. As far as I can see the cup is not a dust cover, although it is referred to as a dust cover on various distributors internet catalogues, which is not correct.

Furthermore, the o-ring will not prevent the ingress of moisture vapour since the existing ozone vents traverse the o-ring and the insulator cup is open at the rear by the cam seal. I will leave it up to you to decide what the function of the o-ring serves, but I would not recommend sealing the distributor cap with silicone sealant as some owners have done. Ozone is produced in higher concentrations when the engine is cold. Ozone production is suppressed to a degree when the engine is hot. However, ozone is highly oxidising, and if it becomes trapped inside the distributor, it will oxidise the HT poles and resin of the distributor caps and cause damage. An increasing concentration of ozone will also inhibit the propagation of the spark in the distributor, which will effectively increase the impedance to earth and consequently increases the load on the ignition coil and ignition module. Expensive damage may ensue if the ozone is not adequately vented.

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ABOUT THE AUTHOR

Rob MacDonald is a Chartered Engineer in the UK and is specialised in the design of hybrid/novel solutions across a broad range of engineering sectors, including prototype development, forensic engineering and trouble shooting.

In his spare time he maintains various classic cars including Mercedes-Benz vehicles from the 1980s and 1990s.

He has worked for a TVR racing team, and has built several race/rally engines, developing racing innovations.

LIMITATIONS

Whilst the I have endeavoured to be reasonably careful, I cannot guarantee that this article is completely free from error, and cannot therefore accept any liability for any consequential or inconsequential loss or damage resulting directly or indirectly from the use of this article.

Users should evaluate the significance and limitations of the results and draw appropriate conclusions for themselves.

The recommended modifications have been road tested for a period of 4 years over the course of approximately 8000 miles, and at the time of writing this article the misfire problems that had once plagued my 1992 Mercedes 500SL have not returned, and there are no signs of carbon tracking in the distributor caps.

The fix has exceeded my expectations.

APPENDIX - ANALYSIS DATA

The data analysis was performed using Microsoft Excel.

The blue figures in the following data represent the actual live data that was recorded.

The figures in black text are calculated values using the equations explained in the THEORY section of this article.

The psychrometric properties such as dew point temperature (tdp) and dry bulb temperature of the air inside the distributor are calculated automatically in Excel using the psychrometric functions (equations) for air.

The minimum dry bulb temperature (tbpmin) required to initiate condensation is calculated iteratively using the in-built 'Goal Seek' function in Excel.

The calculated distributor air temperature is automatically calculated using the standard physics equations for enthalpy, and these values are compared to the minimum dry bulb temperature (tbpmin).

If the calculated minimum dry bulb temperature (tbpmin) is found to be less than the calculated distributor air temperature, the values of distributor air temperature are highlighted in a grey field to denote a theoretical risk of condensation and misfire.

The notes in the left hand column signify key points in the tests i.e. when the engine was switched on/off and also to record observations such as the occurrence of misfires or potential stalling.

RUN #1 - 2017-08-27

	Time t	Relative Humidity	Distributor Cap Temperature t _i	Alloy Recess Temperature T _s	f _(t)	Distributor Air Temp, T _A	Min Dry Bulb to initiate Condensation	Dew Point at Distributor Cap	Condensation Zone for Graph	Moisture Concentration kg/kg air
	mins	%	°C	°C		tbp °C	tbp °C	tdp °C	°C	tdp °C
27/08/2017										
ENGINE START	0	30	14.7	15.1	0.00	15.1	35.0	14.70		0.003
	1	30	15.4	18.2	1.00	16.2	35.9	15.40		0.003
	2.5	30	16.3	21.1	1.00	17.8	36.9	16.30		0.004
	5	31	18	25.7	1.00	20.3	38.3	18.00		0.005
	7.5	32	18.5	30.3	1.00	23.3	38.6	18.50		0.006
	10	32	19.1	35	1.00	25.6	39.0	19.10		0.007
	15	35	26.2	66.1	1.00	39.3	45.4	26.20		0.016
	16	36	28.1	66.7	1.00	43.6	47.0	28.10		0.020
	17	37	32	68.9	1.00	45.6	50.8	32.00		0.024
	18	38	33	70	1.00	48.3	51.4	33.00		0.028
	19	38	34	74.3	1.00	50.7	52.6	34.00		0.032
	20	37	35.6	77.6	1.00	52.7	54.9	35.60		0.034
	21	36	37.2	80.4	1.00	54.9	57.3	37.20		0.037
	22	34	38.7	80.9	1.00	56.0	60.3	38.70		0.037
	23	33	39.5	81.2	1.00	57.0	61.8	39.50		0.037
	24	32	41.1	79.5	1.00	56.7	64.4	41.10		0.036
	25	31	43.1	79.3	1.00	57.5	67.4	43.10		0.036
	26	30	44	79.4	1.00	58.7	69.2	44.00		0.037
	27	29	45	79.8	1.00	59.4	71.2	45.00		0.037
	28	28	46.2	80.3	1.00	60.2	73.5	46.20		0.037
	29	27	47.1	81.2	1.00	61.2	75.4	47.10		0.037
	30	26	48.5	81.3	1.00	61.8	78.0	48.50		0.037
	31	26	49.1	81	1.00	62.5	78.8	49.10		0.038
	32	25	49.4	80.8	1.00	62.7	80.1	49.40		0.037
	33	24	49.6	80.5	1.00	62.8	81.4	49.60		0.035
	34	24	49.5	79.5	1.00	62.4	81.2	49.50		0.035
	35	24	50	79.5	1.00	62.4	81.9	50.00		0.035
ENGINE OFF	40	23	50.2	79.2	1.00	62.5	83.2	50.20		0.034
	42.5	24	50.5	78.9	1.00	62.5	83.0	50.50		0.034
	45	24	50.4	78.5	1.00	62.5	82.4	50.40		0.035
	47.5	25	50.2	78.1	1.00	62.3	81.1	50.20		0.036
	50	23	50	78	1.00	62.1	82.9	50.00		0.033
	52.5	22	49.7	78	1.00	62.0	83.7	49.70		0.031
	55	21	49.6	78	1.00	61.9	84.7	49.60		0.030

RUN #2 - 2018-02-10

	Time t	Relative Humidity	Distributor Cap Temperature t _i	Alloy Recess Temperature T _s	f _(t)	Distributor Air Temp, T _A	Min Dry Bulb to initiate Condensation	Dew Point at Distributor Cap	Condensation Zone for Graph	Moisture Concentration kg/kg air
	mins	%	°C	°C		tbp °C	tbp °C	tdp °C	°C	tdp °C
10/02/2018										
ENGINE START	0	38	4.7	5	0.00	5.0	19.4	4.70		0.002
	1	38	5.4	8	1.00	6.1	20.2	5.40		0.002
	2.5	38	6.3	11	1.00	7.8	21.3	6.30		0.002
	5	39	8	15	1.00	10.0	22.8	8.00		0.003
	7.5	40	8.5	20	1.00	13.2	22.9	8.50		0.004
	10	42	9.1	25	1.00	15.6	22.8	9.10		0.005
	15	47	13.1	30	1.00	18.1	25.4	13.10		0.006
	16	49	14.7	36	1.00	22.9	26.4	14.70		0.009
	17	51	16.7	42	1.00	26.4	27.9	16.70		0.011
	18	53	19.1	55	1.00	33.2	29.9	19.10	53	0.017
	19	55	20.9	57	1.00	35.4	31.2	20.90	55	0.020
	20	55	21.9	57	1.00	36.4	32.2	21.90	55	0.021
	21	53	22.5	60	1.00	38.3	33.5	22.50	53	0.023
	22	48	24.7	65	1.00	40.8	37.7	24.70	48	0.024
	23	45	26.1	66	1.00	42.4	40.4	26.10	45	0.024
Misfire ->	24	42	27.7	67	1.00	43.7	43.5	27.70	42	0.024
	25	39	29	68	1.00	45.0	46.4	29.00		0.024
	26	37	30	68	1.00	45.8	48.6	30.00		0.024
	27	37	31.6	68	1.00	46.3	50.4	31.60		0.024
	28	38	32	68	1.00	47.2	50.3	32.00		0.026
	29	41	33	68	1.00	47.5	49.9	33.00		0.029
	30	45	34	68	1.00	48.0	49.1	34.00		0.033
	31	47	36	68	1.00	48.6	50.4	36.00		0.035
ENGINE OFF	32	48	37	68	1.00	49.8	51.1	37.00		0.038
	33	49	37.2	68	1.00	50.3	50.9	37.20		0.040
	34	49	37	68	1.00	50.4	50.7	37.00		0.041
	35	49	36.9	68	1.00	50.3	50.6	36.90		0.040
	40	44	36.9	68	1.00	50.3	52.8	36.90		0.036
	42.5	40	37	68	1.00	50.3	54.9	37.00		0.033
	45	38	38.4	68	1.00	50.3	57.5	38.40		0.031
	47.5	37	39	68	1.00	51.1	58.8	39.00		0.031
	50	36	39.3	68	1.00	51.5	59.7	39.30		0.031
	52.5	36	39.6	68	1.00	51.6	60.0	39.60		0.031
	55	36	39.6	68	1.00	51.8	60.1	39.60		0.032

RUN #3 - 2018-02-11

	Time t	Relative Humidity	Distributor Cap Temperature t _i	Alloy Recess Temperature T _s	f _(t)	Distributor Air Temp, T _A	Min Dry Bulb to initiate Condensation	Dew Point at Distributor Cap	Condensation Zone for Graph	Moisture Concentration kg/kg air
	mins	%	°C	°C		tbp °C	tbp °C	tdp °C	°C	tdp °C
10/02/2018										
ENGINE START	0	35	7.6	7.6	0.00	7.6	24.1	7.60		0.002
	1	35	7.6	7.6	1.00	7.6	24.1	7.60		0.002
	2	36	7.6	7.6	1.00	7.6	23.6	7.60		0.002
	3	37	8	15	1.00	10.8	23.7	8.00		0.003
	4	38	8.3	17.5	1.00	12.1	23.6	8.30		0.003
	5	39	8.7	23.5	1.00	14.8	23.6	8.70		0.004
	6	40	9.1	24.5	1.00	15.5	23.6	9.10		0.004
	7	41	9.7	30.5	1.00	18.3	23.9	9.70		0.005
	8	42	10.5	33.5	1.00	19.9	24.4	10.50		0.006
	9	43	10.9	36.4	1.00	21.6	24.4	10.90		0.007
	10	44	11.9	39.5	1.00	23.2	25.2	11.90		0.008
	11	45	12.6	43	1.00	25.3	25.6	12.60		0.009
	12	47	13.3	45.6	1.00	26.8	25.6	13.30	47	0.010
	13	49	14.6	49.5	1.00	28.9	26.3	14.60	49	0.012
	14	51	15.8	50.5	1.00	30.0	27.0	15.80	51	0.014
	15	53	17.4	53	1.00	31.8	28.0	17.40	53	0.016
Misfire ->	16	54	19.1	55.4	1.00	33.7	29.5	19.10	54	0.018
	17	53	20.8	57	1.00	35.4	31.7	20.80	53	0.019
	18	51	22.8	59	1.00	37.2	34.5	22.80	51	0.021
	19	49	23.9	60	1.00	38.8	36.5	23.90	49	0.022
Misfire ->	20	46	26.1	62	1.00	40.3	40.0	26.10	46	0.022
	21	42	28.1	63	1.00	42.0	44.0	28.10		0.022
	22	38	29.6	63	1.00	43.1	47.6	29.60		0.021
	23	32	31.2	66	1.00	45.2	52.9	31.20		0.020
	24	29	33.3	67.2	1.00	46.7	57.4	33.30		0.019
	25	27	34.5	67.5	1.00	48.0	60.3	34.50		0.019
	26	26	36.1	67.8	1.00	48.8	63.1	36.10		0.019
	27	26	37.6	68.5	1.00	50.0	64.9	37.60		0.021
	28	26	37.9	70.5	1.00	51.7	65.2	37.90		0.022
	29	27	38.8	71	1.00	52.1	65.4	38.80		0.024
	30	28	39.4	71.5	1.00	52.9	65.3	39.40		0.026
	32.5	32	41.6	71.5	1.00	53.2	65.0	41.60		0.030
ENGINE OFF	35	47	42.8	70.9	1.00	54.2	57.9	42.80		0.047
	37.5	50	44	76	1.00	57.1	57.9	44.00		0.059
	40	50	43.9	75	1.00	57.3	57.8	43.90		0.060
	42.5	49	44.3	74.1	1.00	56.9	58.7	44.30		0.057
	45	47	44.4	74.6	1.00	57.3	59.7	44.40		0.056
	47.5	44	44.3	73.5	1.00	56.9	61.0	44.30		0.051
	50	42	44.1	73.7	1.00	56.9	61.8	44.10		0.048
	60	38	43	68.5	1.00	54.6	62.8	43.00		0.039

RUN #4 - 2018-02-12

	Time t	Relative Humidity	Distributor Cap Temperature t _i	Alloy Recess Temperature T _s	f _(t)	Distributor Air Temp, T _A	Min Dry Bulb to initiate Condensation	Dew Point at Distributor Cap	Condensation Zone for Graph	Moisture Concentration kg/kg air
	mins	%	°C	°C		tbp °C	tbp °C	tdp °C	°C	tdp °C
10/02/2018										
ENGINE START	0	38	5.4	6	0.00	6.0	20.2	5.40		0.002
	1	40	5.6	6	1.00	5.7	19.6	5.60		0.002
	2	42	5.8	7	1.00	6.2	19.1	5.80		0.002
	3	44	6	8.8	1.00	7.1	18.6	6.00		0.003
	4	46	6.6	11	1.00	8.1	18.5	6.60		0.003
	5	48	6.9	15.7	1.00	10.5	18.2	6.90		0.004
	6	49	7.4	23.7	1.00	14.1	18.4	7.40		0.005
	7	50	7.9	26.6	1.00	15.7	18.6	7.90		0.006
	8	51	8.5	31	1.00	17.8	19.0	8.50		0.006
	9	52	9.2	32.7	1.00	18.9	19.4	9.20		0.007
ENGINE OFF	10	53	9.9	33	1.00	19.4	19.9	9.90		0.007
	11	53	11	34	1.00	20.3	21.1	11.00		0.008
	12	53	11.6	36	1.00	21.7	21.8	11.60		0.009
	13	53	12.1	36	1.00	22.1	22.3	12.10		0.009
	14	54	12.7	45.9	1.00	26.6	22.6	12.70	54	0.012
	15	55	13.4	46.5	1.00	27.2	23.1	13.40	55	0.013
	16	59	13.7	47	1.00	27.8	22.3	13.70	59	0.014
	17	62	14.3	51	1.00	29.7	22.1	14.30	62	0.016
	18	67	15.1	51	1.00	30.1	21.7	15.10	67	0.018
	19	70	15.5	51	1.00	30.5	21.4	15.50	70	0.020
ENGINE START	20	74	16.1	51.8	1.00	31.1	21.1	16.10	74	0.021
	21	77	16.8	51.5	1.00	31.3	21.2	16.80	77	0.023
	22	79	17.4	51.5	1.00	31.7	21.4	17.40	79	0.024
	23	81	18.1	51.5	1.00	32.1	21.7	18.10	81	0.025
	24	82	18.6	51.5	1.00	32.5	22.0	18.60	82	0.026
	25	82	19	51.4	1.00	32.7	22.4	19.00	82	0.026
	26	81	19.6	51.2	1.00	32.8	23.2	19.60	81	0.026
	Misfire (S) ->	77	19.4	51.5	1.00	33.3	23.8	19.40	77	0.025
	Misfire (S) ->	72	19.9	52.2	1.00	33.5	25.5	19.90	72	0.024
	29	66	20.5	52.2	1.00	33.8	27.6	20.50	66	0.022
Misfire (S) ->	30	62	20.9	52.9	1.00	34.4	29.1	20.90	62	0.022
	31	60	21.6	52.9	1.00	34.7	30.4	21.60	60	0.021
	32	58	21.8	53.1	1.00	35.1	31.2	21.80	58	0.021
	33	56	22.4	53.7	1.00	35.5	32.4	22.40	56	0.021
	34	53	23.4	54.2	1.00	36.1	34.5	23.40	53	0.020
	35	51	22	54.8	1.00	36.9	33.7	22.00	51	0.020
	36	50	26	55.3	1.00	36.3	38.4	26.00		0.019
	37	42	28.6	57	1.00	39.3	44.5	28.60		0.019
	38	35	30.8	59.5	1.00	41.9	50.6	30.80		0.018
	39	29	32.4	63.8	1.00	45.0	56.3	32.40		0.018
ENGINE OFF	40	25	33.9	66.7	1.00	47.1	61.3	33.90		0.017
	41	21	34.9	69	1.00	49.0	66.4	34.90		0.016
	42	18	35.9	69.6	1.00	49.8	71.2	35.90		0.014
	43	15	36.9	69.7	1.00	50.4	76.8	36.90		0.012
	44	12	38.1	70.2	1.00	51.2	83.9	38.10		0.010
	45	10	39	70.5	1.00	52.0	89.8	39.00		0.009
	46	10	39.9	71.2	1.00	52.8	91.1	39.90		0.009
	47	12	40.5	72	1.00	53.7	87.1	40.50		0.011
	48	20	42.2	72	1.00	54.0	76.6	42.20		0.019
	49	25	42.9	73.7	1.00	55.7	72.2	42.90		0.026
	50	28	42.9	74	1.00	56.3	69.5	42.90		0.030
	55	35	42.9	76.1	1.00	57.2	64.5	42.90		0.040
	60	36	42.7	75.7	1.00	57.0	63.6	42.70		0.041

(S) denotes severe misfires and the engine is on the brink of stalling

RUN #5 - 2018-02-13

	Time t	Relative Humidity	Distributor Cap Temperature t_i	Alloy Recess Temperature T_s	$f_{(t)}$	Distributor Air Temp, T_A	Min Dry Bulb to initiate Condensation	Dew Point at Distributor Cap	Condensation Zone for Graph	Moisture Concentration kg/kg air
	mins	%	°C	°C		tbp °C	tbp °C	tdp °C	°C	tdp °C
10/02/2018										
ENGINE START	0	39	6.7	6.7	0.00	6.7	21.3	6.70		0.002
	1	39	6.8	8	1.00	7.3	21.4	6.80		0.002
	2	40	6.9	9.5	1.00	8.0	21.1	6.90		0.003
	3	41	7.1	14.3	1.00	10.1	20.9	7.10		0.003
	4	42	7.4	18.2	1.00	11.9	20.9	7.40		0.004
	5	43	8	21	1.00	13.2	21.2	8.00		0.004
	6	44	8.5	23.6	1.00	14.7	21.4	8.50		0.005
	7	45	9	28	1.00	16.9	21.6	9.00		0.005
	8	46	9.7	31.6	1.00	18.7	22.0	9.70		0.006
	9	47	10.4	35.4	1.00	20.7	22.4	10.40		0.007
	10	48	11.2	39.2	1.00	22.8	22.9	11.20		0.008
	11	49	12	41.3	1.00	24.1	23.5	12.00	49	0.009
	12	50	12.8	44.9	1.00	26.1	24.0	12.80	50	0.011
	13	51	13.7	47.2	1.00	27.6	24.7	13.70	51	0.012
	14	53	14.8	49.8	1.00	29.2	25.2	14.80	53	0.014
	15	55	16.2	52.3	1.00	30.9	26.1	16.20	55	0.016
	16	58	18.1	55.2	1.00	33.0	27.2	18.10	58	0.019
	17	61	19.8	62.1	1.00	37.0	28.2	19.80	61	0.025
	18	63	21.9	65	1.00	39.2	29.8	21.90	63	0.029
	19	64	24.6	67.1	1.00	41.3	32.4	24.60	64	0.033
Misfire ->	20	64	26.2	69.5	1.00	43.9	34.1	26.20	64	0.038
	21	56	28.3	70.9	1.00	45.4	38.7	28.30	56	0.036
Misfire ->	22	45	30.1	70.5	1.00	46.4	44.8	30.10	45	0.030
	23	35	31.4	69.1	1.00	46.9	51.3	31.40		0.024
	24	30	32.6	69.2	1.00	47.6	55.9	32.60		0.021
	25	25	33.1	68.9	1.00	48.2	60.3	33.10		0.018
	26	23	33.9	69.4	1.00	48.7	63.1	33.90		0.017
	27	23	35	70	1.00	49.4	64.5	35.00		0.018
	28	24	36.1	70.3	1.00	50.2	64.8	36.10		0.019
	29	26	36.9	71.2	1.00	51.2	64.0	36.90		0.022
	30	28	38.6	71.3	1.00	51.7	64.4	38.60		0.024
	31	30	38.9	71.2	1.00	52.6	63.2	38.90		0.027
ENGINE OFF	32	34	39.3	70.8	1.00	52.6	60.9	39.30		0.031
	33	36	39.4	70.1	1.00	52.5	59.8	39.40		0.033
	34	37	39.6	69.4	1.00	52.3	59.5	39.60		0.033
	35	37	39.6	68.5	1.00	52.0	59.5	39.60		0.033
	36	36	39.3	68.2	1.00	51.9	59.7	39.30		0.032
	37	35	38.9	68	1.00	51.6	59.9	38.90		0.030
	38	34	38.6	68.1	1.00	51.4	60.1	38.60		0.029
	39	32	38.7	68.2	1.00	51.3	61.6	38.70		0.027
	40	31	38.6	68.2	1.00	51.4	62.1	38.60		0.026
	41	29	38.7	68.2	1.00	51.3	63.7	38.70		0.025
	42	27	38.4	67.6	1.00	51.1	65.0	38.40		0.023
	43	26	37.6	67.6	1.00	50.9	64.9	37.60		0.022
	44	24	37.3	67.4	1.00	50.4	66.3	37.30		0.019
	45	23	37.2	67.4	1.00	50.2	67.1	37.20		0.018
	46	21	37.6	67.3	1.00	50.1	69.7	37.60		0.017
	47	21	37.1	67.3	1.00	50.4	69.1	37.10		0.017
	48	20	37	67.8	1.00	50.3	70.1	37.00		0.016
	49	19	36.4	68.5	1.00	50.5	70.5	36.40		0.015
	50	18	36.8	68.9	1.00	50.4	72.3	36.80		0.014
	55	14	37	69.1	1.00	50.7	78.6	37.00		0.011
	60	12	38.9	69.5	1.00	51.0	85.0	38.90		0.010
	65	11	40.5	68.9	1.00	51.8	89.4	40.50		0.009
	70	10	39.8	68.7	1.00	52.6	90.9	39.80		0.009
	75	10	39.8	68.7	1.00	52.2	90.9	39.80		0.009
	80	10	39.9	68.7	1.00	52.2	91.1	39.90		0.009
	85	11	39.8	68.7	1.00	52.3	88.4	39.80		0.010
	90	12	39.8	68.5	1.00	52.1	86.2	39.80		0.010

RUN #6 - 2018-02-13

	Time t	Relative Humidity	Distributor Cap Temperature t_i	Alloy Recess Temperature T_s	$f_{(t)}$	Distributor Air Temp, T_A	Min Dry Bulb to initiate Condensation	Dew Point at Distributor Cap	Condensation Zone for Graph	Moisture Concentration kg/kg air
	mins	%	°C	°C		tbp °C	tbp °C	tdp °C	°C	tdp °C
10/02/2018										
ENGINE START	0	35	6.8	6.8	0.00	6.8	23.6	7.11		0.002
	1	35	6.8	7.8	1.00	7.1	23.2	6.80		0.002
	2	36	7	9.3	1.00	7.5	23.0	7.00		0.002
	3	37	7.1	14	1.00	8.9	22.6	7.10		0.003
	4	38	7.3	18.1	1.00	10.1	22.4	7.30		0.003
	5	39	7.8	20.9	1.00	11.0	22.6	7.80		0.003
	6	40	8.3	23.6	1.00	12.1	22.7	8.30		0.004
	7	41	9.1	28.1	1.00	13.7	23.2	9.10		0.004
	8	42	9.8	31.5	1.00	15.2	23.6	9.80		0.005
	9	43	10.3	35.5	1.00	16.8	23.8	10.30		0.005
	10	44	11	39.2	1.00	18.2	24.2	11.00		0.006
	11	45	12.1	41.2	1.00	19.3	25.0	12.10		0.006
	12	47	12.8	44.1	1.00	20.9	25.1	12.80		0.007
	13	49	13.9	47.1	1.00	22.2	25.6	13.90		0.008
	14	51	14.9	49.8	1.00	23.7	26.0	14.90		0.009
	15	55	16.2	56	1.00	26.1	26.1	16.20	55	0.012
	16	57	18.1	59	1.00	27.9	27.5	18.10	57	0.014
	17	58	19.8	62.1	1.00	30.1	29.1	19.80	58	0.016
	18	60	21.9	65	1.00	32.2	30.7	21.90	60	0.018
	19	61	24.6	67.1	1.00	34.3	33.3	24.60	61	0.021
Misfire ->	20	61	26.5	69.5	1.00	36.9	35.3	26.50	61	0.024
	21	61	28.3	71.7	1.00	38.9	37.2	28.30	61	0.027
Misfire ->	22	60	30.1	70.9	1.00	40.0	39.4	30.10	60	0.029
	23	58	31.2	71.2	1.00	41.3	41.2	31.20	58	0.030
	24	54	32.5	69.5	1.00	41.7	43.9	32.50		0.028
	25	50	33.1	69.3	1.00	42.6	46.1	33.10		0.027
	26	42	34	69.4	1.00	43.0	50.5	34.00		0.023
	27	39	35	69.8	1.00	43.8	53.1	35.00		0.023
	28	36	36.2	70.3	1.00	44.7	56.2	36.20		0.022
	29	33	37.1	71.2	1.00	45.8	59.1	37.10		0.021
	30	32	38.5	71.3	1.00	46.5	61.3	38.50		0.021
	31	31	39.1	71	1.00	47.4	62.7	39.10		0.021
ENGINE OFF	32	31	39.4	70.8	1.00	47.8	63.1	39.40		0.022
	33	31	39.6	70.5	1.00	47.9	63.3	39.60		0.022
	34	32	39.5	69.7	1.00	47.8	62.5	39.50		0.023
	35	33	39.4	69	1.00	47.6	61.7	39.40		0.023
	36	33	38.9	69.6	1.00	47.7	61.1	38.90		0.023
	37	34	38.8	68.4	1.00	47.0	60.4	38.80		0.023
	38	34	38.8	68.3	1.00	46.9	60.4	38.80		0.023
	39	34	39	68.2	1.00	46.8	60.6	39.00		0.023
	40	33	38.7	68.2	1.00	47.0	60.9	38.70		0.022
	41	32	38.7	68	1.00	46.7	61.6	38.70		0.021
	42	30	38.4	67.8	1.00	46.7	62.6	38.40		0.020
	43	28	37.6	67.6	1.00	46.4	63.2	37.60		0.018
	44	26	37.3	67.5	1.00	45.8	64.5	37.30		0.016
	45	25	37.3	67.4	1.00	45.5	65.4	37.30		0.016
	46	24	37.4	67.3	1.00	45.5	66.4	37.40		0.015
	47	23	37.2	67.6	1.00	45.7	67.1	37.20		0.014
	48	22	37	67.8	1.00	45.6	67.9	37.00		0.014
	49	21	37	68.5	1.00	45.6	69.0	37.00		0.013
	50	20	36.8	68.9	1.00	45.7	69.8	36.80		0.013
	55	16	37	69.1	1.00	45.6	75.3	37.00		0.010
	60	14	37.5	69.5	1.00	45.9	79.2	37.50		0.009
	65	12	38.6	69.2	1.00	46.2	84.6	38.60		0.008
	70	11	39.8	68.9	1.00	46.9	88.4	39.80		0.007
	75	10	39.8	68.8	1.00	47.7	90.9	39.80		0.007
	80	10	40	68.7	1.00	47.7	91.2	40.00		0.007
	85	11	39.9	68.7	1.00	47.9	88.6	39.90		0.008
	90	11	39.8	68.6	1.00	47.8	88.4	39.80		0.008

RUN #7 - 2018-02-14

	Time t	Relative Humidity	Distributor Cap Temperature T _c	Alloy Recess Temperature T _s	f _(t)	Distributor Air Temp T _A	Min Dry Bulb to initiate Condensation tbp °C	Dew Point at Distributor Cap tdp °C	Condensation Zone for Graph °C	Moisture Concentration kg/kg air tdp °C
	mins	%	°C	°C		tbp °C	tbp °C	tdp °C	°C	tdp °C
10/02/2018 ENGINE START	0	49	6.7	6.7	0.00	6.7	17.6	6.70		0.003
	1	49	6.8	7.5	1.00	6.9	17.7	6.80		0.003
	2	50	6.9	9.5	1.00	7.3	17.5	6.90		0.003
	3	52	7.1	14	1.00	8.3	17.1	7.10		0.004
	4	54	7.3	18.1	1.00	9.3	16.8	7.30		0.004
	5	55	7.6	22.4	1.00	10.3	16.8	7.60		0.004
	6	56	7.9	26.2	1.00	11.3	16.8	7.90		0.005
	7	58	8.3	29.4	1.00	12.2	16.7	8.30		0.005
	8	59	8.8	33	1.00	13.3	17.0	8.80		0.006
	9	61	9.2	34.9	1.00	14.0	16.9	9.20		0.006
	10	62	9.7	38.1	1.00	15.0	17.2	9.70		0.007
	11	63	10.2	40.9	1.00	16.0	17.5	10.20		0.007
	12	64	10.8	43.8	1.00	16.9	17.9	10.80		0.008
	13	65	11.6	46.1	1.00	17.9	18.5	11.60		0.008
	14	65	12.4	48.6	1.00	19.0	19.3	12.40		0.009
	15	64	13.5	51.6	1.00	20.3	20.7	13.50		0.010
	16	64	14.6	54	1.00	21.6	21.9	14.60		0.010
	17	62	16.1	55.4	1.00	22.8	24.0	16.10		0.011
	18	61	17.6	56.7	1.00	24.2	25.9	17.60		0.012
	19	57	18.7	58.4	1.00	25.8	28.2	18.70		0.012
	20	54	20.4	60.2	1.00	27.0	30.3	19.81		0.012
	21	52	21.6	62.2	1.00	28.8	32.2	20.98		0.013
	22	50	22.6	63	1.00	29.9	34.7	22.60		0.013
	23	47	23.3	64.1	1.00	30.9	37.4	24.03		0.013
	24	46	24.4	66.4	1.00	32.0	39.0	25.15		0.014
	25	43	26.3	66.4	1.00	32.8	41.5	26.30		0.014
	26	42	27.3	66.8	1.00	34.4	43.1	27.30		0.014
	27	41	27.8	67.1	1.00	35.3	44.1	27.80		0.015
	28	40	29.4	67.2	1.00	35.7	46.4	29.40		0.015
	29	40	30.3	65	1.00	36.5	48.4	31.21		0.016
	30	39	31.5	65.3	1.00	37.3	49.7	31.96		0.016
	31	37	32.1	65.5	1.00	38.3	50.9	32.10		0.016
	32	36	32.4	64.6	1.00	38.6	51.8	32.40		0.016
	33	34	33.3	65.7	1.00	39.1	54.0	33.30		0.015
	34	33	33.5	65.2	1.00	39.7	54.9	33.50		0.015
	35	31	33.6	65.2	1.00	39.9	56.3	33.60		0.014
	36	31	34.3	65.8	1.00	40.1	57.1	34.30		0.015
	37	30	34.7	66.8	1.00	40.8	58.3	34.70		0.015
	38	28	35.5	66.8	1.00	41.1	60.7	35.50		0.014
	39	27	35.3	66.2	1.00	41.7	61.3	35.30		0.014
	40	25	35.3	66.4	1.00	41.5	63.0	35.30		0.013
	41	25	35.3	68.2	1.00	41.9	63.0	35.30		0.013
	42	24	35.4	68	1.00	41.9	64.0	35.40		0.012
	43	23	35.7	67.3	1.00	41.8	65.3	35.70		0.012
	44	22	35.8	67	1.00	42.0	66.4	35.80		0.011
	45	22	36.2	66.4	1.00	41.9	66.9	36.20		0.011
	46	20	36.5	66.2	1.00	42.2	69.5	36.50		0.010
	47	20	35.9	67.4	1.00	42.7	68.7	35.90		0.011
	48	19	36.3	67.2	1.00	42.2	70.4	36.30		0.010
	49	17	36.5	67.2	1.00	42.5	73.3	36.50		0.009
	50	15	36.2	67	1.00	42.6	75.9	36.20		0.008
	55	12	37.7	68.9	1.00	42.8	83.3	37.70		0.006
	60	10	38.8	69	1.00	44.0	89.5	38.80		0.006
	65	10	38.8	69	1.00	44.9	89.5	38.80		0.006
	70	11	38.8	69.9	1.00	45.0	87.1	38.80		0.007
	75	11	39.3	70.1	1.00	45.1	87.7	39.30		0.007
	80	12	39.2	70.2	1.00	45.5	85.4	39.20		0.007
	85	12	39.1	70.1	1.00	45.4	85.2	39.10		0.007
ENGINE OFF	90	12	39.6	71.2	1.00	45.5	85.9	39.60		0.007