Mark 3 Pump Temperature Testing and Analysis

By

Wesley Throop

Project Engineer

Missoula Technology and Development Center

Background

On July 9, 2009 a crewmember from the Idaho City Hotshots was burned while checking the fuel level in the fuel tank of a Mark 3 pump on the Logging Slash Fire in Alaska. As the crewmember was loosening the cap, he was sprayed with fuel which then ignited causing burns to his face, arms, and hands. Initial reports indicated that the pump had been shutdown prior to the incident but a later interview with the crewmember revealed the pump was operating while the fuel level was being checked.

Photographs taken after the incident showed that the pump appeared to be equipped with a standard Mark 3 fuel tank that had been placed directly in the path of the engine exhaust.

The pump involved in the incident. Note the location of the fuel tank.

Testing

In order to determine the temperatures involved in this incident, MTDC set up a Mark 3 pump to recirculate water in a portable tank. A 5 gallon metal can similar to a Mark 3 pump fuel tank was filled with 4-1/2 gallons of water and placed in approximately the same location as the fuel tank in the incident. The test pump was operated for about 2 hours which is approximately the same amount of time the incident pump was operated. During this time temperatures were measured at the muffler, cylinder head, and water can surface. The exhaust temperature near the water can and the water temperature inside of the can was also measured. Temperatures were taken using an infrared thermometer and a thermocouple probe.

The pump and water can used for testing.
Note exhaust soot on side of water can

Temperatures were taken using a Type K thermocouple
probe (top) and an infrared thermometer (bottom)

The ambient temperature was 87 F at the beginning of the test and 93 F at the end of the test. These temperatures were similar to those at the time of the incident. The temperature of the fuel in the pump fuel tank was 101 F at the beginning of the test. Approximately ½ of a tank of fuel remained at the end of the test.

During the test the muffler temperature stabilized at an average of 932 F and the exhaust temperature near the water can at 278 F. The cylinder/cylinder head temperature varied from approximately 271 F to 335 F depending on where the temperature was taken on the cylinder.   The water can surface temperature climbed from 80 F at the beginning of the test to 196 at the end. The temperature of the water in the can increased from 85 F to 165 F.

Estimated Gasoline Temperatures

Because the amount of water in the can and the initial and final water temperatures are known, the energy absorbed by the water can be calculated. If the water in the can was replaced by gasoline, the gasoline would absorb the same amount of energy.

The heat required to change the temperature of a substance is given by the equation:

$$Q=cm(T_2 - T_1)$$

Where:

Q = energy required to change the substance from its initial temperature to its final temperature

c = the specific heat of the substance. The specific heat is a property of the substance

m = the mass of the substance

T_2 = the final temperature of the substance

T_1 = the initial temperature of the substance

The energy absorbed by the water in the can would be the same amount of energy that would be absorbed if gasoline was in the can.

$$Q_{water} = Q_{gasoline}$$

$$[cm(T_2 - T_1)]_{water} = [cm(T_2 - T_1)]_{gasoline}$$

Rearranging the equations:

$$T_{2\ gasoline} = \{[cm(T_2 - T_1)]_{water} / [cm]_{gasoline}\} + T_{1gasoline}$$

The following values apply:

c_{water} = .998 (Mechanical Engineering Review Manual – 7th Ed)

m_{water} = 8.3 pounds/gallon X 4.5 gallons = 37.4 pounds

$T_{2\ water}$ = 165 degrees F

$T_{1\ water}$ = 85 degrees F
$c_{gasoline}$ = .526 (Mechanical Engineering Review Manual – 7th Ed)

$m_{gasoline}$ = 6.2 pounds/gallon X 4.5 gallons = 27.9 pounds

$T_{1\ gasoline}$ = 101 degrees F

Substituting the above values into the equation for $T_{2\ gasoline}$ gives the following value:

$T_{2\ gasoline}$ = 304 degrees F

This assumes the pump fuel tank contained 4.5 gallons of gasoline. If half a tank of fuel (2.25 gallons, $m_{gasoline}$ = 14 pounds) remained then:

$T_{2\ gasoline}$ = 506 degrees F

The temperature in the pump fuel tank would probably be somewhere between these two values. According to the Tesoro MSDS for gasoline, the boiling point of gasoline can vary between 85 and 437 degrees F depending on the formulation. The temperature calculations indicate it is likely the heat from the engine exhaust caused the gasoline to boil, pressurizing the can more rapidly than it could vent, and forcing liquid fuel and vapor to spray from the vent hole when the cap was loosened. Once the liquid fuel and vapor were released from the fuel tank several potential ignition sources existed at the site to ignite the fuel.

Potential Ignition Sources

It is unknown if the crewmember who was burned was carrying a radio or other portable electronic device at the time of the incident but such devices should not be used in areas where fuel vapor may be present. Page 3 of the GPH Flex Mode Portable Radio User's Manual states: "Do not operate the radio in an explosive atmosphere (petroleum fuels, solvents, dust, etc) unless your radio is an intrinsically safe model designed for such use." In addition, Chapter IV, Page IV-6, Section VI of the January 2004 Interagency Aerial Ignition Guide states: "CAUTION: All hand held electronic devices such as radios, pagers, cell phones, etc. shall be turned off within 50' of any fuel preparation/vapor removal area."

Autoignition due to heating of the gasoline by the engine exhaust is another potential ignition source. The autoignition temperature is defined as the lowest temperature at which a substance will spontaneously ignite in a normal atmosphere without an external source of ignition such as a flame or spark. According to the Tesoro MSDS, the autoignition temperature for gasoline is approximately 495 degrees F. The calculations indicate that it is possible the gasoline temperature could have exceeded the autoignition temperature. Once the fuel tank cap was loosened it may have let enough air into the fuel tank to create a normal atmosphere and cause autoignition of the fuel. Locating the fuel tank away from the engine exhaust would eliminate the possibility of autoignition.

An operating pump engine has several potential sources of ignition including the muffler, exhaust, and electrical system. During testing the muffler temperatures averaged 932 degrees F which is well above the autoignition temperature of the gasoline. It is also possible that a spark from the exhaust system could have ignited the vapor. Because the pump engine has an electrical ignition system, any stray arcing of electricity could ignite the vapor. Two potential sources of electrical arcing are the contacts inside of the pump on/off electrical switch and a damaged ignition lead rubber boot that covers the connection between the ignition lead and the spark plug. This rubber boot was cracked on the pump that MTDC used in the test. All of these ignition sources can be eliminated by shutting down the engine and allowing the exhaust system to cool before opening the fuel tank.

Cracked ignition lead wire boot on Mark 3 pump engine

Spill Containment

Because the pump engine has so many potential ignition sources, it is important to keep the fuel tank as far away from the engine as possible to avoid the ignition of any spilled or leaking fuel or fuel vapors. The spill containment berms that are provided with the pumps force operators to place the fuel tank in close proximity to the pump engine. Because the engine and fuel tank are located in the same spill containment, spilled fuel or a leaking fuel container or line means that the pump engine will be sitting in fuel. Locating the fuel tank in a separate spill containment from the pump would allow the tank to be located further from the engine, reduce the chance of having the fuel tank located near the engine exhaust, and isolate spilled or leaking fuel from the pump engine.

Typical Mark 3 pump and fuel tank installation in a spill containment