Effects of Simulated Fire-Induced Low Oxygen Levels on Engines

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Introduction:

This study examined the effect of low oxygen levels on fuel injected engines.

Figure 1

Historically fire fighting engines have often stalled crossing or working near active fire fronts which may result in the death of firefighters. For instance, in 2010 strong winds pushed a small fire across county lines in Kansas, burning 700 acres of land and a Stafford County Brush truck (Bill Gabbert, 2010)(Figure 1). In 2011, a Kent Volunteer Fire Department fire truck was engulfed in flames after wind shifted while trying to extinguish a field fire in New York (Newstimes, 2011)(Figure 2). In both of these instances, low oxygen levels may have been the cause of engine stalls, however this remains unknown.

Previous research has found oxygen levels as low as 12% associated with wildland fires (Brandt & Elder, 2016). In the current experiment, we tested engine stall parameters under different oxygen levels and different engine RPMs in laboratory conditions.

Figure 2

Results:

Figure 6

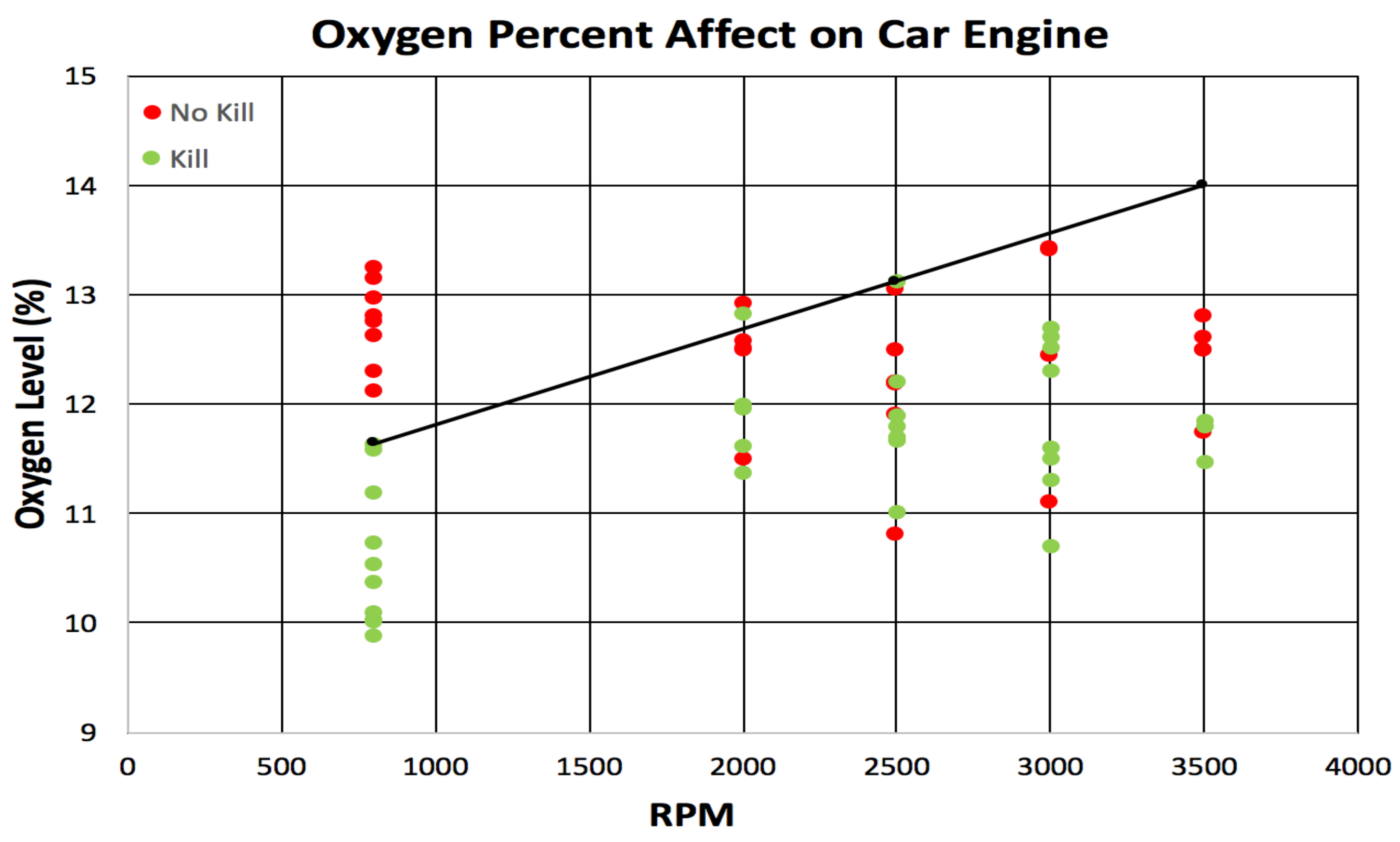

Figure 6. Successful engine stalls are indicated by green dots and unsuccessful stalls are represented by red. The black tend line indicates our projected stall rates from higher RPMs (from 3000-3500RPM). The line is extrapolated with the assumption that a larger bag would allow for successful engine stalling.

HYPOTHESIS

1. Lower levels of oxygen will cause engines to die.
2. As RPM increases, levels of oxygen needed to kill engine will rise.

Methods:

We developed a 100.5L airtight bag (2.09m x .0875m) with a mixing fan and Vernier oxygen probe built in (Figure 3). We filled it with predetermined amounts of ambient air and nitrogen gas from a nitrogen tank to reach a known percentage of oxygen within the bag. After waiting 5 minutes for the bag to equilibrate (Figures 4 and 5), we then clamped one end of the bag to the engine intake manifold of an '04 4-cylinder PT Cruiser while the engine was reeved to the desired RPM. Simultaneously, the air from the bag was pushed from the closed end to the open end, therefore moving the ambient air and nitrogen mix into the engine. Results were recorded (Figure 6).

Figure 4

https://cacamericorps.org/2017/03/09/a-year-on-the-great-smoky-mountains-wildland-fire-module/

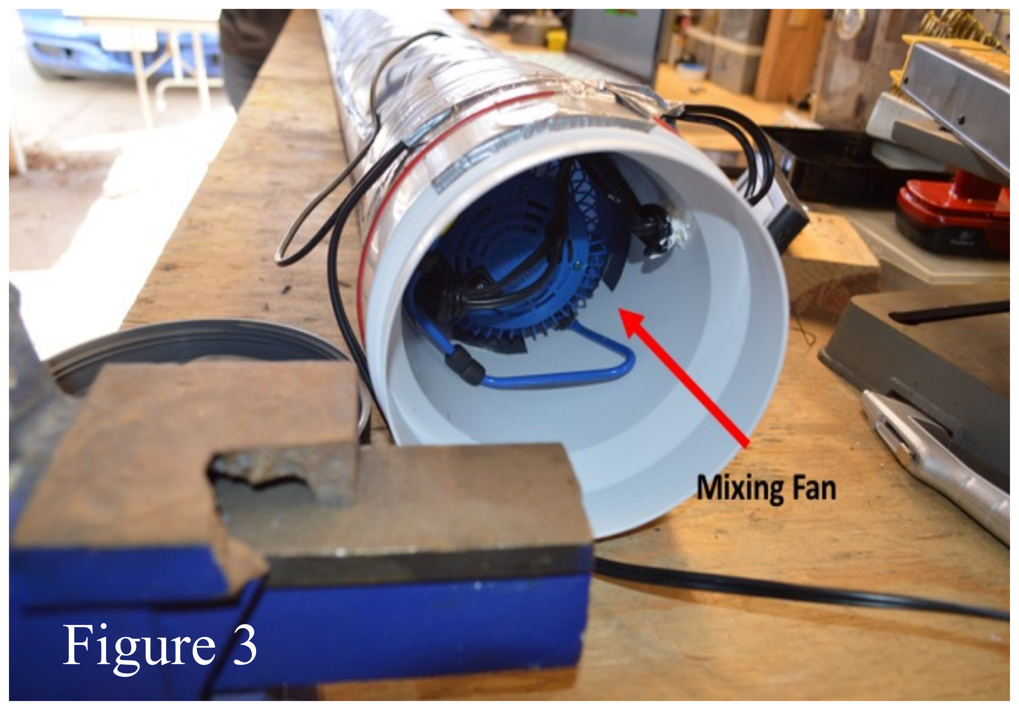

Figure 3

Figure 5

Results:

We found that as RPM goes up, more oxygen is needed to sustain the engine. The engine stalled at 13.12 percent oxygen and 2500 RPM. We would expect the engine to stall at higher oxygen percentages and RPMs, however the bag was of insufficient size to carry the amount of air-oxygen mix needed.

Discussion:

We found that oxygen levels recorded on wildland fires were low enough to stall engines in laboratory conditions. Additionally the engine, under acceleration, appeared to require higher levels of oxygen than engine idling. Stalls were created at 11.6 percent oxygen at 800 rpm and 12.8 percent oxygen at 2,000 rpm (See Figure 6). The air demand at 3,000 and 3,500 rpm by the engine was so great that it exceeded our bag volume in less than 2 seconds. At that point the bag had to be pulled from the manifold so that the bag itself wouldn't block the airflow into the engine. Because of this, the engine was able to take in ambient air and recover from a potential stall.

Measurements in the field and in the lab were atypical of wildfires in that the fires measured in the field were small (4 inches to 3 feet in flame height). It is suspected that larger, more typical wildfires would produce lower oxygen levels than those tested. Additionally, how larger engines cope with low oxygen compared to small engines (we tested a 4cyl) is unknown. While the stoichiometry should remain the same, engine design and torque requirements might provide substantial differences. It is hoped that this research will improve firefighter safety while operating engines near fire lines.

Continued research will need to be conducted in order to develop a working model large enough to test on full size 8 cylinder fire engines. Additionally, we hope to provide firefighters with general cues to read smoke so that they can determine oxygen levels accurately. Anecdotal evidence points to wildland fires being generally oxygen starved and that both fire color and smoke characteristics change with oxygen availability. It is unknown whether this relates to oxygen in the smoke column, but being able to identify bad air might be possible.

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