Anaerobic Operation of an Internal Combustion Engine

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It is shown that an internal combustion engine can be operated in the total absence of oxygen by using fuel which is capable of undergoing thermal explosion.

The experiment described here was conceived after a news report of a fire in Toronto, where the firefighters were unable to effect a rescue because their chain saws died for lack of oxygen; chain saws readily succumb to oxygen starvation when opening up holes in a roof or a floor in order to attack a fire that is established below that level. Clearly, if a gaseous fuel capable of undergoing a thermal explosion can be compressed so as to achieve the critical condition at or about top-dead-centre, an engine could be made to run in a manner analogous to that of a diesel engine, but no air would be necessary to sustain the reaction. Possible fuels might include hydrogen peroxide, methyl isocyanide, ethylene oxide, methyl nitrate, or di-t-butyl peroxide (DTBP); the properties of these five potential 'fuels' are shown in Table 1. From a practical point of view, two of these potential fuels are quite unattractive: hydrogen peroxide is difficult to handle safely, and methyl isocyanide is intensely malodorous; also, methyl nitrate suffers from the disadvantage that a major product of the explosive decomposition is nitric oxide. The principle is demonstrated here using DTBP as the fuel.

A standard Briggs & Stratton 2 H.P. 4-stroke horizontal lawn mower engine (cylinder capacity and compression ratio approximately 100 cc and 5.5 respectively) was modified at the air intake so as to enable the switch over from air to pure nitrogen without inducing strong pressure variations. This was achieved by placing a bubbler and a large ballast volume in the nitrogen line, and the procedure was to open up the nitrogen supply to the intake, closing off the air supply within about a second after this. When the engine was run in the normal manner with regular hydrocarbon fuel, it died as soon as the nitrogen was connected to the air intake, even before the air supply was switched off.

When DTBP was used as a fuel, the engine started easily and ran quite normally; however, when the intake was changed over from air to nitrogen, the engine continued to run smoothly, albeit more slowly. Typically, speeds (measured stroboscopically) would drop from about 900 r.p.m. to about 250 r.p.m.; significant torque was still developed under these anaerobic conditions (although a quantitative measurement was not attempted). Notice that this behaviour occurred when the engine was run as a normal spark engine, but if the spark plug was grounded while the engine was running anaerobically, it would continue to run unevenly and die, very much like an automobile engine does when running on low-octane fuel; however, when running aerobically on DTBP, *this* engine died immediately when the spark plug grounded.

Consider an engine of compression ratio 5.5: if the nitrogen intake is at 300 K, its final temperature after compression, neglecting heat losses, would be almost exactly 600 K, at which temperature, the rate constant for thermal decomposition of DTBP[5] is approximately 100 s^{-1}. Running at 300 r.p.m., each compression stroke lasts approximately 0.1 s, giving sufficient time for the full charge of DTBP to decompose completely within a few degrees of angular motion near top-dead-centre, once it has been ignited by the spark.

It seems that with reasonable safety precautions, practical devices using DTBP† as a fuel can be manufactured; these machines will not die when the ambient atmosphere becomes

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† This engine was unsuitable for use with a gaseous fuel like ethylene oxide, but an attempt to duplicate the behaviour with 1,2-butylene oxide was not successful: the engine died immediately the nitrogen supply was connected to the carburettor. A temperature of about 1000 K is needed to achieve a rate of decomposition of ethylene oxide[6,7] of about 100 s^{-1}, implying a requirement for a compression ratio of about 20.

Table 1. Exothermicity of gaseous thermal explosion reactions.[a]

Substance	Molecular weight (g)	Reaction products	$-\Delta H$ (kcal mol^{-1})	Ref.
H_2O_2	34	$H_2O + ½O_2$	25.2	1
MeNC	41	MeCN	23.7	2
$(CH_2)_2O$	44	$CH_4 + CO$ (or MeCHO	31.5 27.1)	1
$MeNO_3$	77	Complex	~30	3
$(Me_3CO)_2$	146	$C_2H_6 +$ $2Me_2CO$	41.8	4

[a] 1 cal = 4.184 J.

depleted in oxygen, although their power output will fall. The molar heats of combustion of typical octanes[8] and of DTBP[4] are all close to 1300 kcal mol^{-1}, so that for aerobic operation the power developed when using DTBP will not be very different from that developed when using hydrocarbon fuel (assuming, of course, complete combustion in each case). However, when the atmosphere becomes depleted in oxygen, say by a factor of 2, the engine running on DTBP would still develop approximately half the power and with the help of a suitably designed torque converter, could still perform well. In the complete absence of oxygen, the engine will only develop about 3% of the aerobic power, but nevertheless it will still continue to run.

Although we have not demonstrated it beyond reasonable doubt, we believe that it will be possible to construct an anaerobic diesel engine driven by thermal explosions, either for use in mine rescue, or under water, as well as for the use in firefighting that we originally envisaged. This can most easily be achieved by using a rapid-compression ignition device[9–11] to explore the appropriate engine configurations.

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References

1 Selected Values of Chemical Thermodynamic Properties, Technical Note 270-3, U.S. Bureau of Standards, Washington, D.C., 1968.
2 M. H. Baghal-Vayjooee, J. L. Collister, and H. O. Pritchard, *Can. J. Chem.*, 1977, **55**, 2634.
3 P. Gray, J. F. Griffiths, and K. Hasegawa, *Int. J. Chem. Kinet.*, 1981, **13**, 817.
4 G. Baker, J. H. Littlefair, R. Shaw, and J. C. J. Thynne, *J. Chem. Soc.*, 1965, 6970.
5 D. H. Shaw and H. O. Pritchard, *Can. J. Chem.*, 1968, **46**, 2721.
6 W. W. Heckert and E. Mack, *J. Am. Chem. Soc.*, 1929, **51**, 2706.
7 F. P. Lossing, K. U. Ingold, and A. W. Tickner, *Faraday Discuss. Chem. Soc.*, 1953, **14**, 34.
8 J. D. Cox and G. Pilcher, 'Thermochemistry of Organic and Organometallic Compounds,' Academic Press, London, 1970.
9 P. Beeley, P. Gray, and J. F. Griffiths, 'Seventeenth Symposium (International) on Combustion,' The Combustion Institute, 1979, p. 1415.
10 J. F. Griffiths and A. Perche, 'Eighteenth Symposium (International) on Combustion,' The Combustion Institute, 1981, p. 893.
11 J. F. Griffiths and S. M. Hasko, *Proc. R. Soc. London, Ser. A.*, 1984, **393**, 371.