Fly by wire - the ethanol rocket

The whoosh bottle, which we know and love here at SSERC, has become a standard feature in many chemistry classrooms [1]. More recently, a variation has come to light which not only shows the energy changes of the different fuels but puts that energy to use.

The version of this that appeared in a recent Education in Chemistry uses a length of guttering as a guide and fires a fizzy drinks bottle a satisfying distance [2]. Having been looking at this for a while before the EiC article was published we decided to get down to some serious development and soon decided on an important modification.

The SSERC ethanol rocket is projected along a guide cable. There are a couple of advantages of this:

- from a safety perspective, the fact you know the trajectory means it is much easier to ensure there is no risk of the rocket veering off course and hitting someone or something which it shouldn't;
- with the trajectory controlled in this way, it is easier to take good stills/video footage to allow estimates of velocity.

You will need:

- A dry 2-litre PET carbonated drinks bottle, with lid. (The bottle will either say PET or have a '1' inside the recycling triangle)
- 2 screw-in hooks or eyes (if there are no suitable fixings already).
- A length of string or wire (we have been using nylon fishing line).
- A couple of 'runners' (lengths of straw will do though the best we have found are a couple of short lengths of glass tubing).
- A cork borer/glass rod/drill to make the hole on the bottom of the bottle.
- A small bung to fit the hole you make.
- Tape (Sellotape®, masking tape etc.);
- Ethanol **(caution - flammable)**.

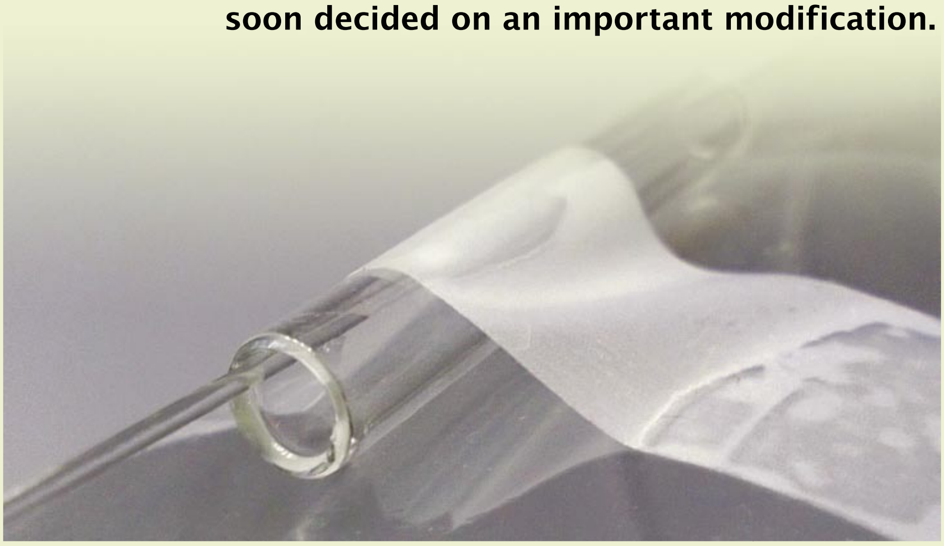


Figure 1 *- Glass 'runners' on the 'wire', fixed to the rocket.*

Preparation

- If there are no fixing points in place, screw the hooks/eyes into somewhere appropriate. A door frame is good for this.
- To make the runners, either cut two sections of straw or break two pieces of glass tubing, roughly 3-4 cm in length, heating the ends to smooth them.
- Slip the runners over one end of the string/wire before fixing.
- Tie the two ends of the string/wire to the hooks/eyes, making sure it is tight. This is especially important if using fishing line as the nylon is elastic and will stretch.
- Make a hole (a heated cork borer is an ideal tool for this) in the base of a 2 litre drinks bottle *ca.* 5-6 mm is a good size.
- Ensure the bottle is dry. Water in the bottle will affect the combustion, leading to disappointing effects.
- Put 0.5 to 1.0 cm^3 of ethanol (IDA or plain purple methylated spirits is quite good enough) into the bottle, insert the bung (or put the lid on depending on which hole you put the fuel in) and shake the bottle to evaporate the ethanol.
- Use the tape to fix the bottle securely to the two runners.

The launch

- Make sure everyone is standing well clear of the flight path, behind the rocket.
- Wearing eye protection, remove the bung from the bottom of the bottle and apply a flame to the opening, using a splint or a Bunsen lighter at arm's length.

The rocket will shoot along the string/wire with a dramatic hiss.

Figure 2 *- Rocket on the move.*

Disposal

If you only use 1 cm^3 (or less) there should be no significant ethanol to dispose of. If you use more, any spare ethanol can disposed of down the sink, followed by plenty of water, before firing the rocket.

Discussion

Dryness of the bottle - the other versions of this we have seen take their lead from the whoosh bottle and insist on a dry bottle. Indeed, several of the whoosh bottle protocols suggest drying for at least 24 hours. This seems to be rather over the top but a dry (or at least fairly dry) bottle works better than a wet one.

Re-use of bottles - if the bottle is showing signs of cracking (or more likely warping from the heat), replace it with a new one (they are not expensive).

If you are short of bottles and want to do a repeat fairly soon after the first rocket, make sure it is cool and blow fresh air through the bottle to remove the accumulated CO_2 that would otherwise interfere with the combustion.

Fuels - this reaction works well with ethanol, methanol and propanol. **Care** should be taken using these flammable solvents, especially with methanol as it is extremely flammable.

Curriculum links

- *CfE* - SCN 3-19a, SCN 4-19a;
- National 4 - Nature's Chemistry - Fuels;
- National 5 - Nature's Chemistry - Energy from Fuels;
- Higher (revised) - Consumer Chemistry - 1c Uses of Alcohols.

Teaching goals will vary with the audience. At its simplest level, this demonstration can show younger students how chemical reactions can release energy that we can use to do useful work, like driving an engine.

At a more advanced level it is possible to time the 'flight' of the rocket and work out its acceleration and thus the energy used. This can then be compared to the energy released in combustion.

Safety

- If this is being done with a single fuel, as a demonstration, ethanol is preferable to methanol for safety reasons as it is less flammable and less toxic. It is quite acceptable, with all due precautions, to use methanol as an alternative, looking at different fuels.
- Propanol will also work.
- The audience and demonstrator should be wearing safety glasses.
- This demonstration should **never** be attempted using a glass bottle.
- **Never** enrich the mixture with oxygen.
- Check the bottle for cracks or melting from previous demonstrations and use another bottle if there is any sign of damage.

Calculations

If you film the rocket, it is possible to do some calculations regarding its flight. You can use Tracker, a program well loved by the Physics department here, or (for the less technically minded) simply count the number of frames taken for the rocket to cross a certain distance. Video editing software that allows you to advance the footage one frame at a time is ideal for this.

Acceleration

A typical test here took 8 frames. As this camera was operating at 25 frames per seconds, that gives 8/25 of a second to cross a distance of 4.75 m, which corresponds to 0.32 seconds.

Starting with $s = ut + 1/2\ at^2$ it is simple, given that $u = 0$, to rearrange the equation to give

$$a = \frac{2s}{t^2}$$

Putting in the figures above gives an acceleration of 121.2 ms^{-2}. This is 12.3 g!

Velocity

Using the same data as used under 'acceleration', a = v/t, which can be rearranged to give v = at

V = 121.2 * 0.32 = 33.9 ms^{-1}
This is over 75 mph!

Energy

Now we have the energy, it is easy to work out the energy required to accelerate the rocket.

$E = 1/2\ mv^2$

The bottle has a mass of 46.3 g = 0.0463 kg

$E = (0.0463 \times 33.9^2) / 2$
$= 26.6\ J = 0.0266\ kJ$

Theoretical energy available

It is possible to estimate this using the bond energies (although we are making several assumptions):

In a 2 litre bottle, 400 cm^3 will be oxygen. At room temperature, an ideal gas has a volume of 24,000 cm^3 per mole. So in the bottle there are 400/24000 moles of oxygen = 0.0167 mol.

$CH_3CH_2OH + 3O_2 = 2CO_2 + 3H_2O$

Bond	Energy (kJ mol^{-1})	Number broken	Energy in (kJ mol^{-1})	Number formed	Energy released (kJ mol^{-1})	Energy released (kJ mol^{-1})
C-H	99	5	495			
C-O	85.5	1	85.5			
O-H	111	1	111	6	666	
C=O	192			4	768	
O=O	119	3	357			
			1048.5		1434	**385.5**

Table 1 *- Bond energies.*

So complete combustion, assuming all the ethanol evaporates, requires 0.0167 ÷ 3 moles of ethanol = 0.0055 mol.

This equals 0.32 cm^3; so the ethanol is in excess and, therefore, oxygen is the limiting factor.

Now look at the bond energies in Table 1.

So the theoretical energy release from the ethanol in our rocket is 385.5 x 0.0167 = 2.12 kJ

Efficiency

It is now possible to see what proportion of the chemical energy available has been used to impart acceleration to the rocket:

(0.0266 / 2.12) x 100 = 1.25%

Conclusions

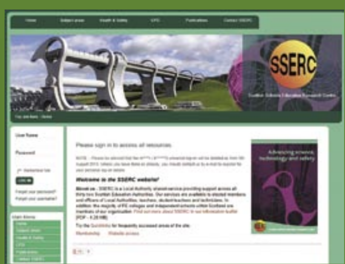
Using a 'wire' to keep the rocket to a known path makes the ethanol rocket a safer classroom activity. It also facilitates easy filming which in turn can be used for some interesting cross-curricular work with the physics and maths departments.

Work with different alcohols gives the surprising result that although the energy per mole increases as you go from methanol to ethanol to propanol, the rocket performance decreases. Speed of combustion is more important in this case that the total energy released.

Important changes to the SSERC website

The normal procedure for logging into the SSERC website is about to change. We are moving away from the generic Member/ XTZA5010 combination.

To continue being able to access www.sserc.org.uk you will need to be issued with your own username/password combination. To obtain your personalised log-in username and password combination email us at registration@sserc.org.uk.



Please make sure that you use a recognisable school email address and include your full name so that we are able to update our database.

References

[1] Education in Chemistry, September 2009 - http://www.rsc.org/Education/EiC/issues/2009Sept/ExhibitionChemistry.asp

[2] Education in Chemistry, May 2013 - http://www.rsc.org/Education/EiC/issues/2013May/ethanol-woosh-rocket-methanol-reaction.asp