Heat release analysis in a variable compression internal combustion engine with butanol

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OBJECTIVES

- To study the behaviour of pure n-butanol as a fuel in a spark ignition engine
- To compare combustion analysis results in a variable compression ratio CFR research engine fuelled with butanol and other fuels as ethanol and commercial gasoline.
- To analyse the knocking behaviour of n-butanol in the CFR engine

HYPOTHESIS

- n-butanol is expected to be a suitable substitute of the ethanol as a biofuel for spark ignition internal combustion engines.
- n-butanol has demonstrated different physical and chemical properties than iso-butanol, being both future biofuels candidates if it could be obtained from waste agro - food wastes by cost - effective techniques.

Butanol properties

Property	Gasoline	Ethanol	Butanol
Carbon number	C4-C12	C2	C4
(RON*MON)/2	97	100	89
Density (kg/dm^3)	0.736	0.790	0.810
L. heating value (kJ/kg)	43.0	26.8	33.0
Stoiquiom. A/F ratio	14.7	9.0	11.2
Boiling Temp. (^{0}C)	24-215	78	118
Latent heat vap. (kJ/kg)	380-500	904	716
Laminar flame speed (cm/s)	51	63.6	58.5
Solubility in water (ml/100ml)	<0.1	Fully	7.7

Single cylinder research engine:

- Variable compression ratio
- Electronic injection
- Cylinder pressure sensor
- Labview data acquisition
- Mathlab data processing

METHODOLOGY

- "Hook" curves to asses n-butanol behaviour as spark ignited fuel
- Combustion and Heat Release analysis based on cylinder pressure data recording was commanded by an external time base with angle encoder of 1800 pulses / revolution.
- Cold start only possible re-fuelling with gasoline
- Self-ignition analysis based on ignition timing for heavy knocking, based on cylinder pressure oscillations analysis along with knocking noise.

Heat Release Analysis

Based on 1º law of thermodynamics for the gas inside the cylinder.

$$\frac{\Delta Q_L}{\Delta\alpha} - p\frac{\Delta V}{\Delta\alpha} + \dot{m}_f \cdot h_f = \frac{\Delta U}{\Delta\alpha}$$

The net heat release rate (ΔQ_n) is: $\frac{\Delta Q_n}{\Delta\alpha} = \frac{\Delta Q_f}{\Delta\alpha} - \frac{\Delta Q_p}{\Delta\alpha} = p\frac{\Delta V}{\Delta\alpha} + \frac{\Delta U}{\Delta\alpha}$

Assuming ideal gas (Heywood, 1988), the heat released by the fuel is:

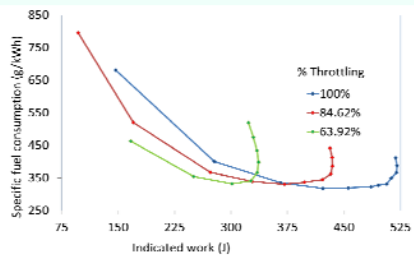
$$\frac{\Delta Q_f}{\Delta\alpha} = \frac{\Delta Q_n}{\Delta\alpha} + \frac{\Delta Q_p}{\Delta\alpha} = \left(1+\frac{C_v}{R}\right) p \frac{\Delta V}{\Delta\alpha} + \frac{C_v}{R} V \frac{\Delta p}{\Delta\alpha} + \frac{\Delta Q_p}{\Delta\alpha}$$

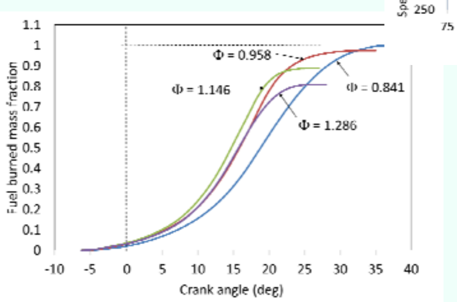
And the mass burning rate can be calculated

RESULTS:

- **"Hook" curves.**

  Indicated thermodynamic work calculated from cylinder pressure and fuel consumption





- **Combustion analysis**

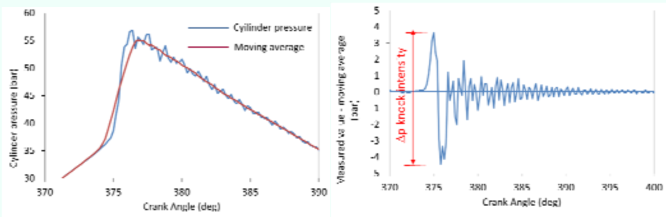
  Fuel burned mass fraction computed from cylinder pressure analysis

Fuel	Ign. timing	W_i (J)	Energy (J)	pmi (kPa)	g/kWh	η_i
Gasoline	10 deg	502	1492	821	253.5	0.337
Ethanol	15 deg	496	1433	810	388.5	0.3495
Butanol	10 deg	505	1474	825	313.9	0.343

RESULTS:

- **Knocking combustion behaviour**

  Fuel burned mass fraction computed from cylinder pressure analysis



Pressure oscillation when knocking. Knock intensity definition..

Ignition angle to obtain 2 bar Δp knocking level

Fuel	O. N.	r = 7	r = 8	r = 9	r = 10
Gasoline	87 - 90	9	4	0	0
Ethanol	100	21	13	7	4
Butanol	86 -89	7	3	0	0

CONCLUSIONS

- n.-butanol is a suitable fuel for spark ignition engines
- Less heating value than gasoline increase absolute fuel consumption but increase
- But reduce indicated thermal efficiency ⇒ less specific fuel consumption.
- Knocking behaviour is similar to gasoline
- But is worse than ethanol
- Lower volatility than gasoline and ethanol ⇒ cold start assistance

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WASTE2FUELS

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