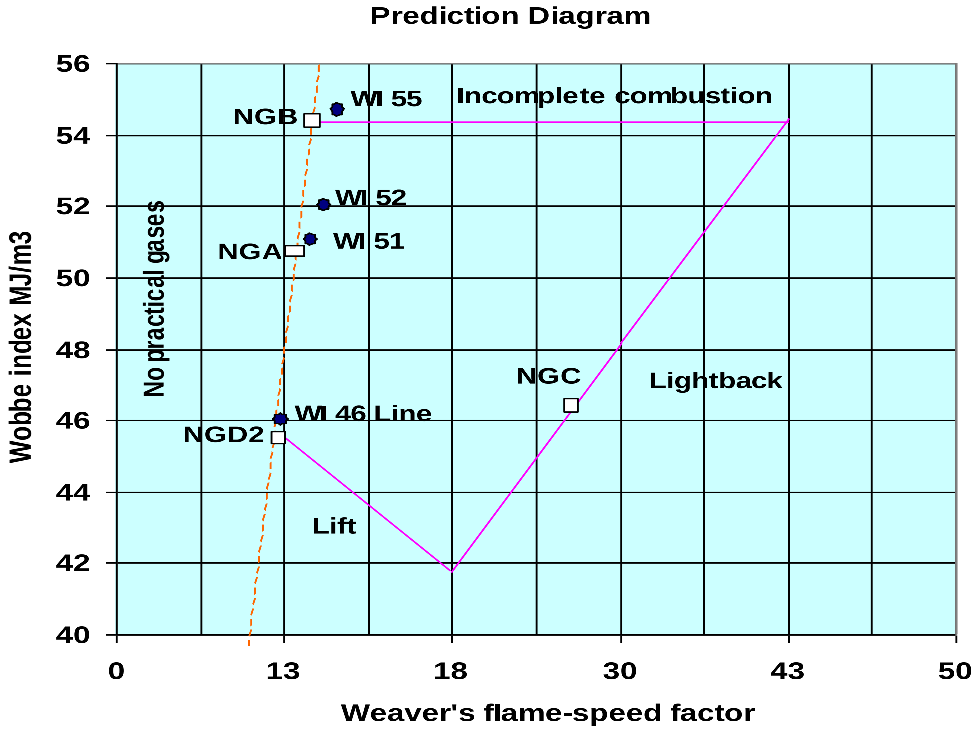
Interchangeability Criteria.

A substitute gas should burn satisfactorily with negligible change in burner performance on all types of burners without the need for special adjustment. The important requirements for satisfactory performance are that, despite some variations in gas composition, the heat input should remain reasonably constant, the flame should remain stable, there should be no significant formation of carbon monoxide or soot and ignition should be satisfactory. It should be appreciated that flame stability, and completeness of combustion, are functions not only of the gas properties but also of burner design

However, some industrial applications pose different problems, such as chemical composition in the operation of exothermic and endothermic protective atmosphere generation, and flame dimensions/ temperature profile in glass working flames. The most reliable method of assessing the interchangeability of an alternative gas supply is to operate in the laboratory the most critical appliances and industrial applications to be found in the district; interchangeability being indicated by the performance on proposed substitute gases after initial adjustment on the reference gas. Unfortunately such methods are time consuming.

The interchangeability of fuel gases has been calculated by the use of different criteria however, at present, it is difficult to know if any one method is totally reliable. The primary reason for this disagreement is that current interchangeability criteria are not fundamental laws but are empirical; thus different gases, and different burner designs, have different limits.

One early diagrammatic system for predicting interchangeability was developed by the British Gas Corporation in which Wobbe number is plotted against Weaver Flame Speed Factor. The diagram is based on a reference gas of pure methane saturated with water vapour at 60°F and 30 in mercury. Any gas lying within the area bounded by the characteristics of the natural gas test gases should be suitable.



The diagram is unable to indicate the sooting propensity of a gas, or the tendency to form polyhedral flames. Subsequently it can only be regarded as a useful method of assessing the potential suitability of a proposed gas composition as it is not complete, nor sufficiently precise to be reliable if a gas falls close to the boundary.

The IGU (International Gas Union) adopted a *Delbourg Interchangeability Index* in which a corrected Wobbe index (Corrected to accommodate varying gas compositions) was plotted against the Combustion Potential of the gas.

Weaver flame speed factor. The Weaver flame speed factor is a convenient measure of the burning velocity of a gas. Although experimental maximum burning velocities are generally more accurate they are difficult to measure and are strongly dependent on the instrument employed.

The Weaver flame speed factor, S. is defined as

$$S = \frac{\sum x_i F_i}{A + 5xN - 18.8x_o + 1}$$

where x_i is the mole fraction of the combustible component i

X_n " inert components

X_o " oxygen in the gas

A is the theoretical (stoichiometric) air per unit volume

$$F_i = \frac{\text{(burning velocity of component i in a stoichiometric air mixture)}}{\text{(burning velocity of hydrogen in a stoichiometric air mixture)}} \times (A_i + 1) \times 100\%$$

A_i = theoretical (stoichiometric) air per unit volume for component i.

Values of F_i were taken from Weaver

Delbourg (I. G. U.) Interchangeability Indices. The indices given here are as defined by the International Gas Union). They apply to gas mixtures belonging to the 2nd family.

The corrected Wobbe number, W', is defined as

$$W' = K_1 K_2 Q / d^{0.5}$$

where Q is the gross C.V. in millithermies/m^3 (NTP)

d is relative density (S.G.)

K_1, K_2 are correction factors which depend on gas composition.

The Combustion Potential, C, is given by

$$C = \frac{u ([H_2] + 0.3 [CH_4 + 0\ 7 [CO] + v\sum a_i [C_nH_m]_i)}{d^{0.5}}$$

where $[H_2$, $[CH_4]$, [CO] and $[C_nH_m]_i$ are the percentages by volume of hydrogen, methane, carbon monoxide and higher hydrocarbons respectively.

v is a function of W'
u is a correction factor which depends on the oxygen content of the gas
a_i is a coefficient for the higher hydrocarbon component i.

The Yellow-tip Index, I_y, is given by

$$I_y = \frac{k \sum m_i [A]_i}{d^{0.5}}$$

where $[A]_i$ is the percentage of hydrocarbon component i (including CH_4)

m_i is a coefficient of component i

k is a correction factor which depends on the oxygen content of the gas.

All coefficients and correction factors were taken from "Aide Memoire du Gaz"

The necessary criteria in this system for interchangeability of two natural gases are that they should both lie within the relevant domain of interchangeability , which is a plot of W' against C. I_y should be less than 210, and the hydrogen content is less than 10%.

	G20 Methane	G21 NGB	LNG North African	Mean North Sea
CV (nett) MJ/m^3	34.02	40.90	46.48	35.05
CV (gross) MJ/m^3	37.78	45.16	51.12	38.86
Wobbe	50.73	54.7	57.41	50.40
Delbourg interchangeability				
Corrected Wobbe	12790	13880	14020	12790
Combustion Potential	40.27	44.28	50.08	41.67
Yellow tipping	134.2	180.9	213.1	143.30

The current UK criteria for supplied gas to the network uses an interchangeability diagram with axes of Wobbe and an equivalent C_3H_8 + N_2 mixture. This technique is outlined in the "Gas Safety (Management) Regulations 1996

Current UK Requirements based on the "Gas Safety (Management) Regulations 1996 are given in brief detail below.

CONTENT AND OTHER CHARACTERISTICS OF GAS UNDER NORMAL CONDITIONS

Content or characteristic	*Value*
hydrogen sulphide content	$\leq$ 5 mg/m^3
total sulphur consent	$\leq$ 50 mg/m^3
hydrogen content	$\leq$ 0.1% (molar)
oxygen content	$\leq$ 0.2% (molar)
impurities	shall not contain solid or liquid material which may interfere with the integrity or operation of pipes, meters, regulators or appliances which a consumer could reasonably be expected to operate
hydrocarbon dewpoint + water dew point	shall not be at such levels that they do interfere with the integrity or operation of pipes, meters, regulators or ap
WN	(i) $\leq$ 51.41 MJ/m^3, and (ii) $\geq$ 47.20 MJ/m3
ICF	$\leq$ 0.48
SI	$\leq$ 0.60

REQUIREMENTS FOR GAS CONVEYED TO PREVENT A SUPPLY EMERGENCY

(a) WN (i) $\leq$ 52.85 MJ/m^3, and
(ii) $\geq$ 46.50 MJ/m^3

(b) ICF ≤ 1.49;

"ICF" means the Incomplete Combustion Factor;
"SI" means the Soot Index;
"WN" means the Wobbe Number;

ICF, SI and WN are calculated in accordance with the following formulae

$$ICF = \frac{WN - 50.73 + 0.03PN}{1.56}$$

$$SI = 0.896 \tan^{-1} (0.0255\, C_3H_8 - 0.0233N_2 + 0.617)$$

$$WN = \frac{\text{calorific value}}{\text{relative density}^{0.5}}$$

There is also a "Lift Index" (LI) which is not a requirement of the UK regulations

$$LI = 3.25 - 2.41\tan^{-1} \{(0.122).(WN - 36.8 - 0.0119PN)\}$$

A LI of ≤ 2.13 would be regarded as a upper limit.

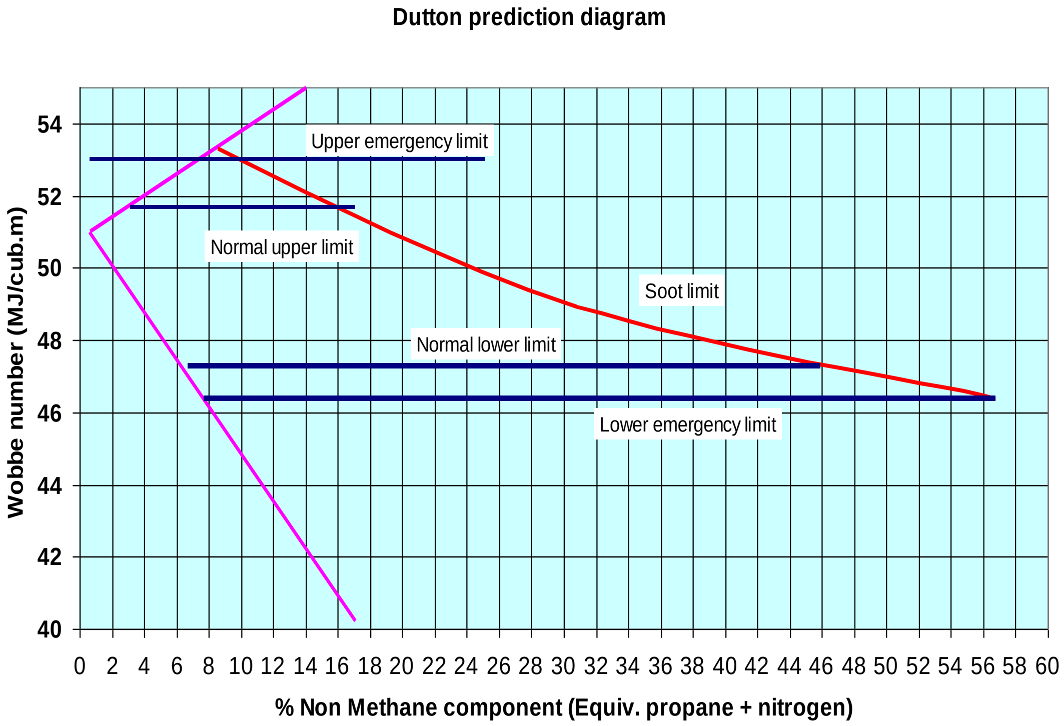
Where "PN" means the sum of the percentages by volume of propane and nitrogen in the equivalent mixture;
And "equivalent mixture" means a mixture of methane, propane and nitrogen having the same characteristics as the gas being conveyed and calculated as follows:

(i) the hydrocarbons other than methane and propane are expressed as an equivalent amount of methane and propane which has the same ideal volume and the same average number of carbon atoms per molecule as the said hydrocarbons,

(ii) the inert gases, including nitrogen, are expressed as equivalent amounts of nitrogen which, when mixed with all the non-inert components of the gas being conveyed (in their existing ratios) gives a Wobbe Number equal to the Wobbe Number of the original gas (real, gross)

(iii) the equivalent amounts calculated from (i) and (ii) above are added to the methane and propane of the gas being conveyed and rationalised to 100% to give the equivalent mixture;

Acceptable gas mixtures (Interchangeability) are those which lie within the bounds of the Dutton prediction diagram.



Conclusions.

The three types of interchangeability diagram were all primarily developed for the Type A domestic appliance area, and appliances are tested to these criteria. The British Gas (Prigg) diagram shows the limit or test gases to mark the boundaries of incomplete combustion, lift, lightback and the reference gas (NGA). These gases are still the standard for the UK, the NGB gas (G21) for incomplete combustion is the "high" Wobbe gas of 54.7 and is very similar to the WI55 gas. In our experience the appliance manufacturers allow a safety limit to make sure that their equipment has acceptable performance on G21.

The Delbourg prediction method would also accept a G21 gas under the "yellow tipping" criteria (i.e. soot or incomplete combustion) (See above table). As a comparison in this table we have shown a LNG gas with a very high Wobbe which would be classed as outside the yellow tipping range but was considered on the limit for the UK in the early days of natural gas.

The current UK gas supply regulations use the Dutton prediction diagram, and is very conservative with an upper Wobbe emergency limit of 52.85. This is a supply criteria rather than an appliance limit.