FLASH POINTS OF AQUEOUS SOLUTIONS OF FLAMMABLE SOLVENTS

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Many fine chemicals and pharmaceutical intermediates are processed using flammable solvents which are soluble in water. The disposal of such solutions of solvents as waste can be problematical, particularly as dilute aqueous solutions can be expensive to incinerate. Disposal to an effluent treatment plant can be hazardous if the solution is above its flash point. Hence the availability of the flash point of aqueous solutions of flammable solvents would be useful for selecting an appropriate disposal route. Whilst such data of actual measurements of aqueous solutions are valuable, a predictive method would also be useful, and the data of three solvents have been compared to simple theoretical models, to allow prediction to be undertaken using readily available spreadsheets or calculating tools, rather than using dedicated specialist software for physical property prediction. The decision to avoid proprietary prediction software was taken deliberately to make the method easily applicable to users in small and medium enterprises (SMEs) who may not have access to such specialised programmes. The correlations obtained were good, with actual flash points being within 5 K of the predicted values. Tables of measured values are presented for 18 common solvents.

INTRODUCTION

The measurement of flash point of solutions can be difficult and time consuming. The most common flash-point apparatus, the Pensky-Martens closed-cup flash point tester[1], is suitable for pure substances, and is not suitable for a two component mixture, as this will change in composition as the testing proceeds, thus giving a false high flash-point. Therefore an equilibrium method is required, such as the Setaflash Closed Cup method[2], or the standard single-component method must be modified to an equilibrium method. Once flash point data is available for several aqueous mixtures of any one solvent, it is comparatively simple to draw a curve through the known data points and interpolate to any desired value. However, obtaining the initial flash-point data is time consuming and requires access to the flash-point testing apparatus. Therefore a simple method of predicting the flash-point of a solution of solvent in water was required, using vapour-liquid equilibrium data and pure component flash-point data readily available in the literature. The approach of using a simple prediction method using the minimum of data is ideal for SMEs who often do not have access to sophisticated physical property data prediction software, and only have access to the open published literature.

FLASH POINT

The flash point of a liquid is the temperature at which the liquid has sufficient vapour pressure to just form a flammable atmosphere in equilibrium with the liquid. Clearly for a single component, such as acetone, the vapour concentration at the flash point corresponds directly with the lower flammable limit. This will also apply to a multi-component mixture where all the components are flammable.

However, in a binary mixture where one of the components is flammable and the other is water, there is inevitably water vapour present as well as the flammable vapour. Where there is a small quantity of water vapour present, the flammable material dominates and the lower limit concentration will be reached at just a little over the temperature of the flash point of the pure flammable liquid.

Where the water is present at a high concentration, there are two factors involved. Firstly, the concentration of the flammable vapour is depressed by the effect of the water in the solution, and the water vapour itself reduces the partial pressure of the oxygen in the air within the flash-point apparatus. Hence there will be a concentration where despite there being enough flammable vapour present to be above the lower flammable limit, there is insufficient partial pressure of oxygen present. Thus it can be difficult to determine whether the mixture is above its flash point but has insufficient oxygen to burn, or whether it is simply below its flash point.

METHOD OF MEASURING FLASH POINT

The flash points were determined using a Sommer and Runge PMA2 Automatic Pensky-Martens Closed Cup Flash Point Tester supplied by Gallenkamp. The procedure used was similar to that described in the relevant British[3], American[4] and European[5] Standards. However, as the standard Pensky-Martens Closed Cup Flash Point Tester is designed for single components only, a modified procedure was used.

The standard method for single-component mixtures heats the sample at a rate of 1 K per minute whilst being stirred. A small flame is dipped into the flash-point tester cup periodically, and if there is sufficient vapour, a flash of flame occurs. The testing by dipping the flame into the cup is initiated typically between 20 K and 40 K below the expected flash point. The temperature at which this occurs is recorded as the flash point. As a single component liquid will give off a vapour of exactly the same composition as the liquid, any vapour lost between successive tests will have no effect on the composition of the remaining liquid.

Where a two or more component liquid is tested in the same fashion, the vapour will be richer in composition with the more volatile component. In the case of flammable solvents, this will usually be the solvent rather than the water. Hence if the standard test is carried out, starting some 20 K below the expected flash point, the loss of the more volatile component will alter the composition significantly. In the case of the solvent being the more volatile component, the recorded flash point will be far higher than the true flash point.

In order to avoid this potential error, the technique was modified to estimate the flash point as normal so as to initially determine an approximate value for the flash point. This approximate value can then be used to set the flash point tester so that it will start testing just below the approximate flash point using a fresh sample. Successive approximations lead to the situation where a fresh sample will flash immediately on testing at one temperature, yet will not flash if tested only 2 K below. This allows the Pensky-Martens method to approximate to an equilibrium method for multi-component mixtures.

SELECTION OF SOLVENTS

The solvents selected, 18 in all, were chosen on the basis that many were commonly used in the fine chemicals and pharmaceutical sector, although some are frequently used in other sectors as well. Since solvents which are insoluble in water exhibit a substantially constant flash-point irrespective of the concentration of the two-phase solvent-water mixture, only completely miscible and partially miscible solvents were selected. All were flammable, and a range of pure component flash points was selected to cover the range from −40°C to +57°C with a reasonable coverage of the range. Details of the solvents are contained in Table 2. In the table, the solubility is described as "total" where it is completely miscible, "partial" where the solubility is not complete, but is more than 10% v/v, and "slight" where the solubility is less than 10% v/v. Note that some of the solvents classed as "slight" form two-phase liquid mixtures over a large part of the range, be it at one end or in the middle.

EXPERIMENTAL

Solutions of each solvent were prepared by mixing water and the solvent together, with the quantities being measured by volume. This was both for convenience, and to minimise the time that the solvent was evaporating, as this would affect the final composition. The composition in volume-volume concentrations can be converted to mass-mass concentration by using the equation:

$$W = \frac{100 \times (V_s \times \rho_s)}{(V_s \times \rho_s) + (V_w \times \rho_w)} \tag{1}$$

Where:

W = weight concentration of solvent %(w/w).
V_S = volume of solvent
ρ_S = density of solvent
V_w = volume of water
ρ_w = density of water

For all practical purposes, the density of water can be taken as unity, so the equation can be reduced to $W = (V_s \times \rho_s)/(V_s \times \rho_s) + V_w$. The samples were prepared by mixing at ambient temperature, and were then tested for flash point, using the modified testing procedure outline above. The results are contained in Appendix 1 for reference.

There were some inconsistencies which gave difficulties during the testing. The first of these were where the liquids formed two phases. Over the two-phase region, there was little variation in flash point with composition, although some liquids, such as methyl ethyl ketone (MEK, 2-Butanone), exhibit retrograde solubility, in that a single phase solution at ambient temperature forms two separate phases when heated[6]. Where this has occurred, it is noted in the Appendix. Similarly, there are cases where two phases at ambient temperature form a single phase when heated to the flash point, but this has no affect on the flash-point since it is single phase at the test temperature.

Further complications occurred for *tert*-butanol (2-methyl-2-propanol) which is a solid at the flash point of 11°C, and melts at approximately 26°C. To determine the flash point of the pure material, molten liquid was put into the Setaflash apparatus, and cooled to well below the solidifying temperature before testing. The addition of 10% by volume of water to the pure molten liquid lowered the freezing point to below ambient, so this allowed testing to be undertaken more readily for the water-containing samples.

Finally, the tetrahydrofuran solutions were difficult to test as, upon cooling, those containing less than 10% water formed ice crystals at sub-zero temperatures, altering the liquid phase composition. This continued until the concentration of the water exceeded about 90%, by which time the flash-point had reached +6°C, and sub-cooling of the liquid below 0°C was not necessary to determine an accurate flash point.

PREDICTION OF FLASH POINT

For a single component, the vapour concentration at the flash-point corresponds to the lower flammable limit. Hence when the flash point is known, it is easy to use vapour pressure data from the literature[6,7] to determine the vapour concentration by partial pressure.

Although there are many commercial software packages available to predict physical properties, many such programmes are not available to small and medium enterprises (SMEs), and many are temporal, in that the current version becomes obsolete in a few years and will no longer run on today's computer platforms. Therefore a method was sought which did not rely on specific commercial software, so as to be future-proofed. However, it was considered that a spreadsheet would be useable to solve the equations rapidly and plot the flash-point versus concentration curves, and as such would not be reliant on any specific software package.

Whilst there is little available data on measured flash-points of aqueous solutions, it was thought desirable to have a method where the flash point of any composition of an aqueous solution could be predicted from readily available data, typically the pure liquid flash point and some data on the vapour liquid equilibrium available from the literature[8,9]. This data would be used to predict when the vapour composition of the flammable component reaches the lower flammable limit, as this would correspond to the flash-point. As much data is isobaric, some correction would have to be applied to take account of the variation in temperature between the data available and the predicted flash point[10].

Where vapour-liquid equilibrium data are not available, it would be necessary to have some predictive method to determine the vapour liquid equilibrium data. This again would require a prediction method, and the method of van Laar[11] was deemed to be simple, and require the minimum of data, although the use of other more sophisticated methods such as the Wilson, NTRL (Non Random Two Liquids) or UNIQUAC (UNIversal QUasi-chemical Activity Coefficients), would be more accurate but generally require more data than is commonly available. Clearly where more data are available, it would be better to use a more sophisticated and hence more accurate method, but the objective of this work was to find a simple predictive method that required the absolute minimum of data, which would generally be available in common data sources such as Lange's Handbook of Physics and Chemistry[12], Perry's Chemical Engineers' Handbook[13], or International Critical Tables[6]. Tables of azeotropic systems are available in papers by Horsley[14,15].

SYSTEMS WHERE *x-y-t* DATA ARE AVAILABLE

The calculation method is best illustrated by an example calculation, as this allows easy use simply by substituting data values into the method. The data available for methanol is suitable. Selected smoothed vapour-liquid equilibrium data[16] for methanol-water at 730 to 750 mm Hg is as in Table 1 below.

The vapour pressure at any temperature can be calculated from the simple Antoine formula:

$$\log_{10} p_{\mathrm{mm}} = -\frac{0.05223}{T}\mathrm{A} + \mathrm{B} \tag{2}$$

Table 1. Vapour–liquid equilibrium for methanol–water at 760 mm Hg

Mole % Methanol in		
Liquid	Vapour	Temp°C
0	0	100
2	13.4	96.4
4	23.0	93.5
6	30.4	91.2
8	36.5	89.3
10	41.8	87.7
15	51.7	84.4
20	57.9	81.7

Table 2. Properties of solvents selected

Solvent	Flash Point °C	Boiling Point °C	Solubility
Acetaldehyde	−40	21	Total
Tetrahydrofuran (THF)	−21	65.5	Total
Methyl Acetate	−18	57.5	Slight
Methyl Ethyl Ketone (MEK)	−6	80	Partial
Acetonitrile	5	81.5	Total
2,3-Butanedione	8	88	Partial
Methanol	9	65	Total
2-Propanol	14	82.4	Total
Tert.Butanol	12	83	Total
p-dioxane	12	101	Total
Methyl IsoButyl Ketone (MIBK)	15	118	Slight
Allyl Alcohol	22	97	Total
1-Propanol	23	97	Total
2-Butanol	22	98	Slight
Isobutanol	30	108	Slight
Cyclohexylamine	28	134	Total
1-Butanol	37	117	Slight
Morpholine	35	129	Total
Acetic Acid	39	116	Total
Ethylene Glycol Isopropyl Ether	46	143	Total
N,N-Dimethyl Formamide (DMF)	58	153	Total

where p_{mm} is the vapour pressure in mm Hg, the constants A and B for methanol are 38324 and 8.8017 respectively[17] and T is the absolute temperature. Since the flashpoint of methanol at 760 mm Hg is 9°C, this corresponds to a vapour pressure of

$$\log_{10} p_{\mathrm{mm}} = -\frac{0.05223}{273.2 + 9} \times 38324 + 8.8017 = 1.7086. \quad \therefore p_{\mathrm{mm}} = 50.5 \text{ mm Hg}$$

and this corresponds to a lower flammable limit of $(50.5/760) \times 100 = 6.65\%$ v/v which compares well with the literature value[18] of 6.7% v/v.

If a 4 mole % solution of methanol is considered, then the vapour above this solution will contain 23 mole % at the boiling point of 93.5°C, i.e. a partial pressure of $(23/100) \times 760 = 174.8$ mm Hg. As the lower flammable limit is 6.7 mole %, it corresponds to the partial pressure of 50.5 mm Hg. Therefore, it is necessary to estimate the temperature at which the partial pressure of the methanol above the 4 mole % solution is 50.5 mm Hg. This is a simplification which relies on the relative volatility between the methanol and the water not changing appreciably with temperature. This is a reasonable assumption when the vapour pressures are low, and far removed from the critical temperature or pressure, which is the case for methanol and water. The temperature at which the partial pressure of the methanol above the solution reaches 50.5 mm Hg is determined from the pure component vapour pressure of 174.8 mm Hg at the boiling point of the solution for which the vapour-liquid equilibrium data is obtained. At 93.5°C, the vapour pressure of methanol is 2203 mm Hg, so the temperature at which the solution has a partial pressure of 50.5 mm Hg and just becomes flammable would have a pure-component vapour pressure of $(50.5/174.8) \times 2203 = 636$ mm Hg. This corresponds to a temperature of 60.5°C obtained by solving the Antoine equation. As the solution contained 4 mole %, it is necessary to convert to mass concentration, using the equation:

$$W = \frac{100 \times (M_s x_s)}{M_s x_s + M_w x_w} \tag{3}$$

so the mass concentration for 4 mole % of methanol (mol. weight 32) and water (mol. weight 18) corresponds to $W = (100 \times (32 \times 0.04))/(32 \times 0.04 + 18 \times 0.96) = 6.90\%$ by weight. This same calculation can be repeated for all the known vapour-liquid equilibrium data available, to give a range of calculated flash points versus concentration. These are plotted in Figure 1 along with the measured values amended to a weight-weight basis.

As methanol is completely miscible with water, the same method was used with a highly non-ideal system of 1-butanol and water. This exhibits partial solubility and forms

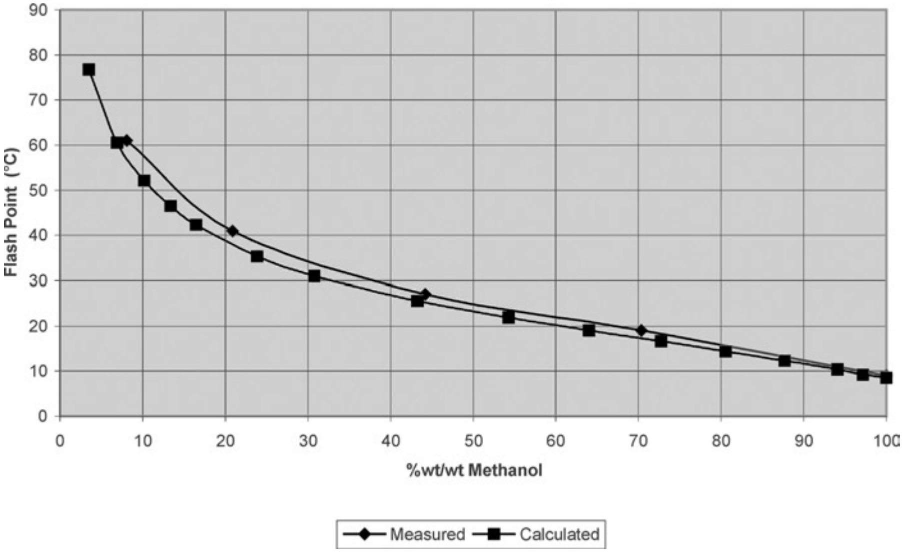

Figure 1. Methanol flash point variation with concentration

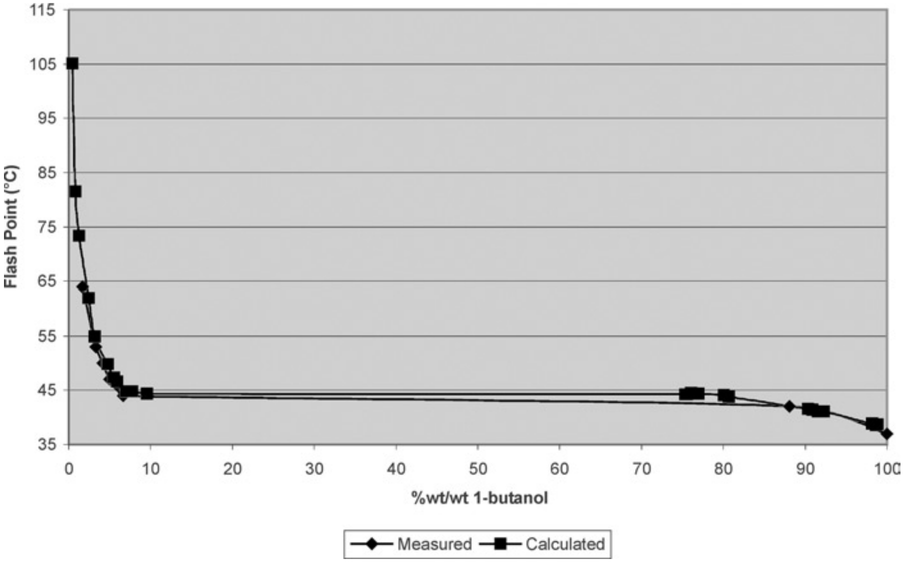

Figure 2. 1-Butanol flash point variation with concentration

an azeotrope. However, using the published vapour-liquid equilibrium data[8], a graph of flash-point versus concentration can be plotted using the same method. This is shown in Figure 2, and again shows a good correlation.

SYSTEMS WHERE *x-y-t* DATA ARE NOT AVAILABLE

In this case, as vapour-liquid equilibrium data are not available, it is necessary to use a predictive method to estimate the vapour-liquid equilibrium, and then apply the same method as above. As another example, this has been carried out for a solution of p-dioxane. We chose dioxane as there was no vapour-liquid equilibrium data readily available, but both azeotropic data and Antoine equation vapour pressure data were available. The mixture is reported[14] to form an azeotrope containing 18% w/w water, boiling at 87.8°C. As it is necessary to determine the vapour concentration in equilibrium with the liquid, a predictive method such as van Laar's method can be used where the liquid is single phase. The method of van-Laar, whilst not particularly accurate, has the advantage of requiring only one experimental point since it is a two-constant equation. In this example, the data point of the azeotrope is used to estimate the vapour-liquid equilibrium. The azeotrope is very useful as it is easier to obtain an accurate vapour composition than with a non-azeotrope.

Firstly, the vapour-liquid equilibrium data is estimated. The activity coefficients at the azeotropic concentration are calculated first as:

$$\gamma_s = \frac{P}{p'_s} \tag{4}$$

and

$$\gamma_w = \frac{P}{p'_w} \tag{5}$$

Since y_s and x_s are equal at the azeotrope, then the two values can be substituted into the van Laar equations to give:

$$a = \ln\gamma_s\left(1 + \frac{x_w}{x_s}\frac{\ln\gamma_w}{\ln\gamma_s}\right)^2 \tag{6}$$

and

$$b = \ln\gamma_w\left(1 + \frac{x_s}{x_w}\frac{\ln\gamma_s}{\ln\gamma_w}\right)^2 \tag{7}$$

from this the final equations for activity coefficient are:

$$\ln\gamma_s = \frac{a}{\left(1 + \frac{a}{b}\left(\frac{x_s}{x_w}\right)\right)^2} \tag{8}$$

and

$$\ln\gamma_w = \frac{b}{\left(1 + \frac{b}{a}\left(\frac{x_w}{x_s}\right)\right)^2} \tag{9}$$

The vapour composition at an estimated boiling temperature can now be calculated from the expressions:

$$y_s = \frac{\gamma_s\, p'_s x_s}{P}$$
$$y_w = \frac{\gamma_w\, p'_w x_w}{P} \tag{10}$$

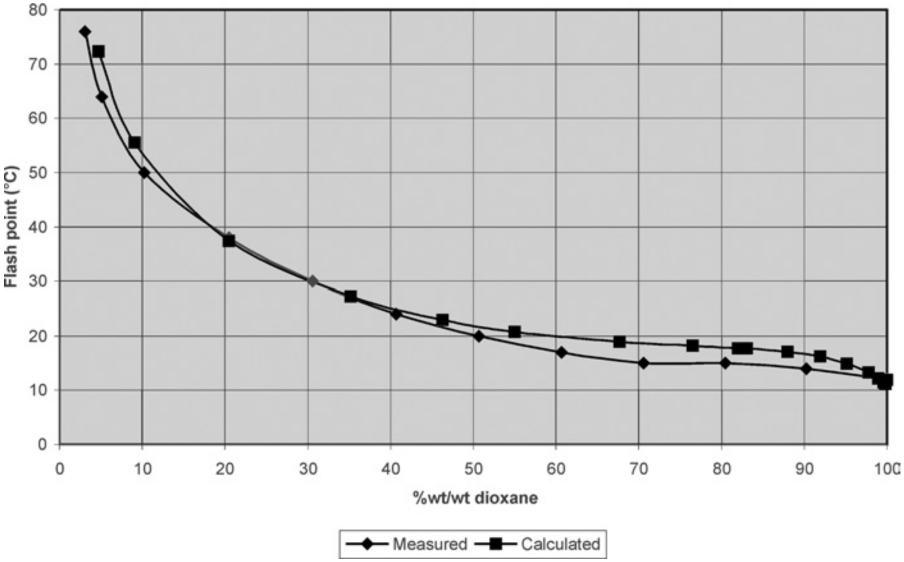

Figure 3. p-Dioxane flash point variation with concentration

If the sum of the mole fractions of the solvent and water does not equal 1.0, then the boiling temperature is adjusted until the sum of the mole fractions does equal 1.0. This now gives the vapour-liquid-equilibrium/temperature data required for the estimation of flash point, and the calculation is continued as before where the vapour liquid equilibrium data were available. The calculations were carried out on a spreadsheet, and the calculated flash points for dioxane-water are displayed in Figure 3.

DISCUSSION

The data presented in Appendix 1 for the 18 solvents is actual measured data. The determination of the flash point itself did present some difficulties in a practical sense. Firstly, as explained above, the need to use an equilibrium method necessitated modifying the standard test methods given in the American, British or European standards. The modification to the method does mean that the Standards are not adhered to strictly, and hence anyone not familiar with the problems of two-component mixtures could easily be misled into measuring a false high flash point. At the limit, a flash may not be detected at all, since the loss of the volatile component can be significant unless a "go/no-go" test criterion is applied with a fresh sample used for each test. Whilst this is a valid extension to the test method, it is not in accordance with the Standards, and hence must be detailed with the reported results.

The lower strength solutions presented practical problems, in that when the solution boiled in the standard cup, the boiling liquid overflowed from the cup, and entered the heating element and the apparatus itself. On the early tests, this damaged the equipment, so a modified cup was used with a annular guard lip around the cup to catch the liquid boiling over. Again, this does not strictly conform to the standards, but as it is external to the geometry of the cup itself, it does not affect the result. Standard single components flashed at the same temperature in both the guarded and standard cups. A photograph of the guarded and standard cups is shown in Figure 4.

Further complications occurred with two samples, as indicated above. Firstly, *tert*-butanol and dioxane are unusual in that they exhibit a flash point below the melting point. Clearly, this cannot be tested in a standard Pensky-Martens flash point apparatus, as there is a stirrer which cannot be used for a solid. Hence the Setaflash equilibrium tester was used. The solid material was melted, and the pure liquid placed in the cup and cooled until it was frozen. The cup was then allowed to warm up, and the flash-point was determined for the pure component. For the aqueous solutions, the molten liquid was added to water, and allowed to dissolve. The addition of a small quantity of water was sufficient to lower the freezing point to below the flash point, and so the Pensky-Martens tester could then be used for the subsequent tests.

The testing of tetrahydrofuran was complicated by the formation of ice-crystals. Here, the solution exhibited a rapid change in solubility of the water with respect to temperature, and ice crystals formed in the solution upon cooling below zero. Since the aim of this work was to determine the flash point of aqueous solutions, principally

Figure 4. Flash point apparatus modified cup (left) and standard cup (right)

for determining whether effluent streams were flammable, the work only considered those solutions where the flash point was above 0°C, i.e. where the tetrahydrofuran concentration was less than 10% v/v. This behaviour is unusual in that most solutions of solvents with water act as an antifreeze, as in ethanol, methanol and ethylene glycol, all of which depress the onset of formation of ice crystals well below zero Celsius.

When undertaking the prediction of flash point, it was decided that a simple approach would be preferable, as if this gave acceptable results it would be easy and quick and would only require reference to standard readily available text-books and reference works, which would generally be available to SMEs. The use of the two-coefficient Antoine equation for vapour pressure prediction was used as the data set in International Critical Tables[6] was based on this form. Obviously Antoine equations with three or more constants can be used with this method, but the overall accuracy is obviously dependant on the accuracy of the vapour liquid equilibrium data as well.

The use of the van Laar prediction of vapour-liquid equilibrium is only the simple option chosen here – other methods would probably be equally suitable, but no work was undertaken to establish whether more accurate predictive methods for vapour-liquid equilibrium would give more accurate predictions of flash point. This work could be undertaken in future if time permits. The work of Liaw et al uses a more complex model, but does so only where both substances are flammable.

CONCLUSIONS

- Closed-cup flash point data are presented for aqueous mixtures of 18 common solvents.
- A predictive method using vapour-liquid equilibrium data and pure-component vapour pressure data has been developed which gives acceptable results for predicting the flash point of aqueous solutions.
- Where only vapour pressure data and a single azeotrope composition are available, a further predictive method has been shown to provide an acceptable estimation of the flash-point of an aqueous solution.
- The simple approach used will be of benefit to small and medium sized enterprises who may not have access to sophisticated predictive tools and software.
- The methods above are suitable for calculating using standard spreadsheets on computers.
- The method does not rely on specific commercially available software, as hand calculation methods can also be used.

NOMENCLATURE

a	arbitrary constant in the van Laar equation
b	arbitrary constant in the van Laar equation
M	molecular weight

P	atmospheric pressure
p	vapour pressure, mm Hg
V	volume
W	weight %
x	mole fraction in liquid
y	mole fraction in vapour

Greek

γ	activity coefficient
ρ	density

Superscripts

$'$	pure component

Subscripts

s	solvent
w	water

APPENDIX 1

FLASH POINT DATA FOR AQUEOUS SOLVENT MIXTURES

Notes:

All data obtained from in-house testing at Blackley

NFTB = No Flash to Boil

* = Tested on a Setaflash flash-point tester as the material is a solid at the indicated temperature

Acetaldehyde

Concentration %v/v	Flash Point ±2°C
100	−40
5	+14
2	31
1	45
0.5	66

Acetic Acid

Concentration %v/v	Flash Point ±2°C
100	39
90	50
88	NFTB

Acetonitrile

Concentration %v/v	Flash Point ±2°C
100	5
5	45
3	60
2	NFTB

Allyl Alcohol

Concentration %v/v	Flash Point ±2°C
100	22
90	27
80	29
70	30
60	31
50	32
40	33
30	35
20	39
10	49
5	61
4	NFTB

2,3-Butanedione (Diacetyl)

Concentration %v/v	Flash Point ±2°C
100	8
35	11
30	18
20	19
10	29
5	41
2	56
1	NTFB

1-Butanol

Concentration %v/v	Flash Point ±2°C
100	37
90	42
#	#
8	44
7	46
6	47
5	50
40	53
2	64
1	NFTB

Two-phase between 8 and 90% v/v

2-Butanol

Concentration % v/v	Flash Point ±2°C
100	22
90	27
#	#
10	34
5	43
2	64
1	NFTB

Two-phase between 8 and 90% v/v

***iso*-Butanol (2-Methyl-1-Propanol)**

Concentration %v/v	Flash Point ±2°C
100	30
90	34

(*Continued*)

***iso*-Butanol (2-Methyl-1-Propanol)**

Concentration %v/v	Flash Point ±2°C
#	#
8	34
5	40
3	48
2	55
1	NFTB

Two-phase between 8 and 90% v/v

***t*-Butanol**

Concentration %v/v	Flash Point ±2°C
100*	12
90	15
80	17
70	18
60	18
50	19
40	20
30	21
20	24
10	32
5	43
2	57
1	NFTB

Cyclohexylamine

Concentration %v/v	Flash Point ±2°C
100	28
90	36
80	44
70	52
60	55
50	55
40	55
30	56
20	56
10	55
5	55
3	58
2	NFTB

N,N-Dimethyl Formamide

Concentration %v/v	Flash Point ±2°C
100	58
90	70
88	73
86	76
84	79
83	NFTB

1,4-Dioxane

Concentration %v/v	Flash Point ±2°C
100*	12
90*	14
80	15
70	15
60	17
50	20
40	24
30	30
20	38

(*Continued*)

1,4-Dioxane

Concentration %v/v	Flash Point ±2°C
10	50
5	64
3	76
2	NFTB

2-Isopropoxyethanol (Ethylene glycol isopropyl ether)

Concentration %v/v	Flash Point ±2°C
100	46
90	56
80	61
70	64
65	NFTB

Methanol

Concentration %v/v	Flash Point ±2°C
100	9
75	19
50	27
25	41
10	61
5	NFTB

Methyl Acetate

Concentration %v/v	Flash Point ±2°C
100	−18#
8	7
6	11
5	13
4	16
3	22
2	30
1	46
0.5	63
0.4	NFTB

#Setaflash

1-Propanol

Concentration %v/v	Flash Point ±2°C
100	23
90	28
80	30
70	31
50	31
30	32
20	35
10	43
5	52
4	54
3	57
2	68
1	NFTB

2-Propanol

Concentration %v/v	Flash Point ±2°C
100	14
90	18

(*Continued*)

2-Propanol

Concentration %v/v	Flash Point ±2°C
80	19
70	21
60	21
50	21
40	23
30	25
20	30
10	41
5	50
2	65
1	NFTB

2-Butanone (Methyl Ethyl Ketone)

Concentration %v/v	Flash Point ±2°C
100	−6
#	#
30	−2
20	+2
10	11
5	20
2	36
1	50
0.5	64
0.3	NFTB

Morpholine

Concentration %v/v	Flash Point ±2°C
100	35
90	41
80	49
70	57
60	69
55	75
50	NFTB

MIBK (4-Methyl-2-Pentanone)

Concentration %v/v	Flash Point ±2°C
100	15
#	#
2	20
1	31
0.5	43
0.3	57
0.2	NFTB

Insoluble above 2%

Tetrahydrofuran

Concentration %v/v	Flash Point ±2°C
100	−21
#	#
10	+6
4	22
3	26
2	33
1	46
0.5	62

#Sample formed ice when cooled

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