Distillation Curves for Alcohol-Gasoline Blends

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SUPPORTING INFORMATION

S.1 Estimation of azeotropic point for alcohol-gasoline blends

Most of the distillation curves for the alcohol-gasoline blends showed a plateau followed by sharp upwards transition in the curve. This transition point is considered to be the point at which the alcohol has been completely distilled from the liquid, which some refer to as the azeotropic point. We estimated the azeotropic point as the distillate volume percentage corresponding to the inflection point in the distillation curve immediately after plateau. In this region, there was also a temporary but significant increase in heater temperature and instability in the distillation rate. The azeotropic point for blends with low concentrations of the butanol isomers could not be discerned (i.e., no obvious inflection point or change in heater temperature), presumably due to

their greater non-polar nature as compared to the shorter-chain alcohols. Likewise, there was no apparent inflection point for the highest concentration alcohol blends (85%) for all alcohols.

In general, the azeotropic point increases with increasing alcohol concentration and with the boiling point of the alcohol. The lowest azeotropic point for methanol blends occurred at the lowest distillation fraction for a given alcohol concentration (by volume). Ethanol and 2-propanol (having very similar boiling points) behaved similarly for all alcohol concentrations, while the azeotropic point for the other alcohols was shifted to higher distillate volume fractions (i.e., the azeotropic point increased with increasing boiling point of the alcohol for a given alcohol concentration).

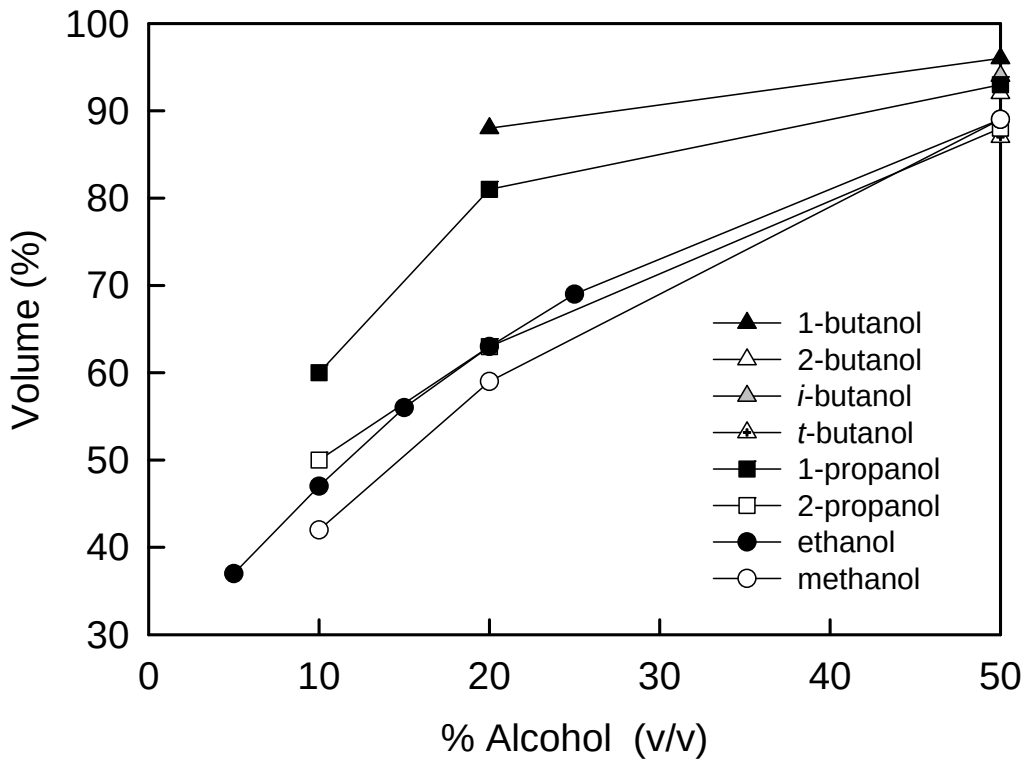

Figure S-1. Estimated azeotropic points from distillations of single-alcohol blends with gasoline.

S.2 D86 Distillation temperature data

Gasoline	
	Temperature (°C)
Initial boiling point (IBP)	32.5 ± 0.1
5%	46.5 ± 0.3
10%	54.1 ± 0.2
15%	60.2 ± 0.1
20%	66.4 ± 0.3
30%	81.5 ± 0.5
40%	97.7 ± 0.3
50%	105.5 ± 3.0
60%	111.3 ± 2.3
70%	116.6 ± 1.3
80%	130.4 ± 0.7
85%	143.4 ± 0.3
90%	159.6 ± 0.4
95%	167.6 ± 0.3
Final boiling point (FBP)	198.4 ± 1.1

Table S-1. Experimental D86 distillation temperature measurements for Haltermann EEE gasoline. Values are averages and standard deviations from triplicate measurements.

	Temperature (°C)			
	M10	**M20**	**M50**	**M85**
IBP	34.2 ± 0.4	33.8 ± 0.6	35.7 ± 0.1	46.9 ± 0.4
5%	43.4 ± 0.2	43.7 ± 0.1	46.2 ± 0.3	58.6 ± 0.1
10%	46.2 ± 0.1	46.7 ± 0.1	49.7 ± 0.2	61.4 ± 0.0
15%	48.6 ± 0.0	49.3 ± 0.1	53.7 ± 0.1	62.6 ± 0.0
20%	50.8 ± 0.0	51.7 ± 0.1	56.9 ± 0.1	63.1 ± 0.0
30%	54.9 ±0.0	56.4 ± 0.8	60.6 ± 0.1	63.6 ± 0.0
40%	61.6 ± 1.1	59.2 ± 0.1	61.8 ± 0.1	63.8 ± 0.0
50%	103.2 ± 0.3	61.0 ± 0.1	62.4 ± 0.1	64.0 ± 0.0
60%	109.6 ± 1.1	97.1 ± 0.3	63.0 ± 0.1	64.1 ± 0.1
70%	116.7 ± 0.2	113.1 ± 1.4	63.5 ± 0.2	64.2 ± 0.0
80%	127.8 ± 0.2	123.9 ± 0.1	63.8 ± 0.1	64.3 ± 0.0
85%	139.6 ± 0.6	133.4 ± 1.6	64.1 ± 0.1	64.4 ± 0.0
90%	157.9 ± 0.4	153.1 ± 0.3	125.1 ± 1.0	64.5 ± 0.0
95%	167.2 ± 0.1	166.1 ± 0.0	161.1 ± 0.7	64.8 ± 0.0
FBP	195.7 ± 1.1	195.1 ± 1.8	185.0 ± 2.6	66.9

Table S-2. Experimental D86 distillation temperature measurements for methanol blends with gasoline. Values are averages and standard deviations from duplicate or triplicate measurements. Not all measurements generated FBP values, thus not all FBP values include standard deviations.

	Temperature (°C)						
	E5	**E10**	**E15**	**E20**	**E25**	**E50**	**E85**
IBP	33.7 ± 0.5	34.1 ± 0.1	34.0 ± 0.1	35.3 ± 0.1	36.1 ± 0.6	39.8 ±0.6	51.8 ± 0.6
5%	46.5 ± 0.1	48.4 ± 0.2	49.1 ± 0.1	50.4 ± 0.2	50.5 ± 0.4	57.6 ± 0.3	70.7 ± 0.4
10%	51.0 ± 0.1	52.7 ± 0.1	53.6 ± 0.1	54.7 ± 0.1	55.6 ± 0.1	62.6 ± 0.6	74.6 ± 0.2
15%	54.3 ± 0.2	56.0 ± 0.1	57.1 ± 0.1	58.4 ± 0.1	59.2 ± 0.1	66.6 ± 0.7	76.0 ± 0.1
20%	57.5 ± 0.0	59.3 ± 0.1	60.5 ± 0.1	61.8 ± 0.1	62.9 ± 0.1	69.8 ± 0.6	76.6 ± 0.1
30%	66.0 ± 0.4	65.0 ± 1.0	66.6 ± 0.1	67.9 ± 0.1	68.8 ± 0.1	73.6 ± 0.1	77.0 ± 0.1
40%	90.5 ± 0.1	71.0 ± 0.7	71.3 ± 0.4	72.1 ± 0.0	72.6 ± 0.1	75.1 ± 0.1	77.3 ± 0.1
50%	104.4 ± 0.9	98.8 ± 0.0	75.5 ± 0.4	74.2 ± 0.5	74.5 ± 0.2	76.0 ± 0.2	77.5 ± 0.1
60%	110.1 ± 2.4	110.4 ± 0.5	106.5 ± 0.4	77.9 ± 0.5	75.7 ± 0.6	76.7 ± 0.1	77.7 ± 0.1
70%	117.6 ± 0.2	116.9 ± 0.2	115.6 ± 0.2	111.5 ± 0.4	94.3 ± 0.3	77.3 ± 0.2	77.8 ± 0.0
80%	128.8 ± 0.6	127.2 ± 0.4	125.5 ± 0.1	124.4 ± 0.2	122.1 ± 0.1	77.8 ± 0.2	78.0 ± 0.1
85%	140.9 ± 0.6	138.4 ± 0.7	136.4 ± 0.0	134.4 ± 0.6	132.3 ± 0.1	78.6 ± 0.3	78.1 ± 0.1
90%	158.8 ± 0.7	157.2 ± 0.3	156.3 ± 0.0	154.1 ± 0.1	151.9 ± 0.3	113.5 ± 0.4	78.2 ± 0.1
95%	167.6 ± 0.4	166.9 ± 0.6	166.8 ± 0.2	166.5 ± 0.2	166.1 ± 0.3	160.6 ± 0.5	78.6 ± 0.2
FBP	194.3 ± 4.1	195.8 ± 2.1	194.0 ± 1.2	193.8 ± 0.3	192.5 ± 0.8	187.7 ± 1.1	79.2 ± 0.1

Table S-3. Experimental D86 distillation temperature measurements for ethanol blends with gasoline. Values are averages and standard deviations from duplicate or triplicate measurements.

	Temperature (°C)			
	1-Pr10	**1-Pr20**	**1-Pr50**	**1-Pr85**
IBP	31.9 ± 0.3	34.1 ± 0.1	36.9 ± 0.3	51.6 ± 0.1
5%	47.2 ± 0.3	50.1 ± 1.1	59.6 ± 0.6	88.0 ± 0.1
10%	54.6 ± 0.1	58.2 ± 0.7	69.3 ± 0.6	92.2 ± 0.1
15%	59.9 ± 0.0	64.2 ± 0.6	77.1 ± 0.2	93.8 ± 0.0
20%	65.0 ± 0.1	70.2 ± 0.7	83.2 ± 0.1	94.4 ± 0.2
30%	75.9 ± 0.1	81.1 ± 0.5	89.4 ± 0.1	95.2 ± 0.0
40%	84.8 ± 0.1	87.4 ± 0.2	91.8 ± 0.1	95.6 ± 0.0
50%	90.8 ± 0.1	90.0 ± 0.2	93.1 ± 0.1	95.9 ± 0.1
60%	103.6 ± 0.1	91.6 ± 0.3	94.1 ± 0.1	96.1 ± 0.1
70%	116.0 ± 0.4	92.9 ± 0.1	95.3 ± 0.1	96.2 ± 0.0
80%	126.9 ± 0.5	105.5 ± 2.3	96.5 ± 0.0	96.4 ± 0.0
85%	137.8 ± 1.0	129.8 ± 0.8	97.2 ± 0.1	96.5 ± 0.0
90%	156.7 ± 0.7	151.1 ± 0.7	98.5 ± 0.1	96.7 ± 0.1
95%	167.0 ± 0.3	165.2 ± 0.2	161.0 ± 0.0	97.0 ± 0.0
FBP	195.3 ± 0.1	192.6 ± 1.2	187.0 ± 1.3	104.7 ± 0.3

Table S-4. Experimental D86 distillation temperature measurements for 1-propanol blends with gasoline. Values are averages and standard deviations from duplicate measurements.

	Temperature (°C)			
	2-Pr10	**2-Pr20**	**2-Pr50**	**2-Pr85**
IBP	33.2 ± 0.5	34.4 ± 0.8	38.2 ± 0.7	53.4 ± 1.1
5%	48.3 ± 0.9	51.2 ± 0.4	59.2 ± 0.1	75.8 ± 0.3
10%	53.8 ± 0.6	56.6 ± 0.4	65.1 ± 0.0	78.5 ± 0.1
15%	57.9 ± 0.5	60.7 ± 0.3	69.6 ± 0.0	79.7 ± 0.0
20%	61.7 ± 0.4	64.6 ± 0.2	73.3 ± 0.1	80.3 ± 0.0
30%	69.2 ± 0.4	71.6 ± 0.2	77.6 ± 0.2	80.8 ± 0.0
40%	76.5 ± 0.5	76.4 ± 0.3	79.1 ± 0.4	81.1 ± 0.0
50%	94.5 ± 1.0	79.5 ± 0.5	80.2 ± 0.1	81.3 ± 0.0
60%	109.2 ± 0.7	84.9 ± 1.6	80.7 ± 0.1	81.5 ± 0.1
70%	115.7 ± 1.2	111.9 ± 0.4	81.3 ± 0.1	81.6 ± 0.0
80%	126.6 ± 0.6	124.2 ± 0.2	82.4 ± 0.1	81.9 ± 0.0
85%	138.1 ± 0.4	134.2 ± 0.5	83.8 ± 0.1	82.2 ± 0.0
90%	156.6 ± 0.3	153.9 ± 0.7	126.5 ± 1.1	82.6 ± 0.0
95%	167.1 ± 0.3	166.1 ± 0.3	159.8 ± 0.5	83.6 ± 0.0
FBP	193.8 ± 0.9	188.9 ± 0.9	186.8 ± 0.2	90.6 ± 0.7

Table S-5. Experimental D86 distillation temperature measurements for 2-propanol blends with gasoline. Values are averages and standard deviations from duplicate or triplicate measurements.

	Temperature (°C)			
	1-Bu10	**1-Bu20**	**1-Bu50**	**1-Bu85**
IBP	32.2 ± 0.3	33.6 ± 0.2	36.4 ± 0.1	49.9 ± 0.4
5%	50.0 ± 0.5	51.5 ± 1.1	61.4 ± 0.9	103.2 ± 0.7
10%	58.0 ± 0.1	61.0 ± 0.7	74.6 ± 0.7	110.4 ± 0.1
15%	64.3 ± 0.3	68.3 ± 0.5	85.7 ± 0.4	112.5 ± 0.1
20%	71.0 ± 0.4	75.7 ± 0.6	94.9 ± 0.4	113.5 ± 0.1
30%	85.3 ± 0.4	90.2 ± 0.2	104.4 ± 0.1	114.5 ± 0.1
40%	96.4 ± 0.2	99.2 ± 0.2	108.3 ± 0.2	115.3 ± 0.0
50%	102.1 ± 0.1	103.4 ± 0.3	111.1 ± 0.0	115.7 ± 0.0
60%	105.4 ± 0.4	106.3 ± 0.0	113.5 ± 0.1	115.9 ± 0.0
70%	110.1 ± 0.4	109.4 ± 0.1	115.4 ± 0.2	116.1 ± 0.0
80%	123.3 ± 0.4	114.1 ± 0.3	116.6 ± 0.1	116.2 ± 0.0
85%	138.0 ± 0.4	120.4 ± 0.3	117.2 ± 0.1	116.3 ± 0.1
90%	157.5 ± 0.1	153.1 ± 0.8	117.8 ± 0.0	116.3 ± 0.0
95%	167.2 ± 0.1	166.4 ± 0.5	122.8 ± 0.5	116.6 ± 0.0
FBP	193.8 ± 0.4	188.7 ± 3.5	180.4 ± 0.4	127.5 ± 0.4

Table S-6. Experimental D86 distillation temperature measurements for 1-butanol blends with gasoline. Values are averages and standard deviations from duplicate or triplicate measurements.

	Temperature (°C)			
	2-Bu10	**2-Bu20**	**2-Bu50**	**2-Bu85**
IBP	33.4 ± 0.9	33.1 ± 0.8	37.0 ± 0.3	51.2 ± 1.1
5%	49.5 ± 1.3	51.1 ± 0.8	59.7 ± 1.4	90.0 ± 0.4
10%	56.7 ± 0.7	59.0 ± 0.9	71.3 ± 0.8	94.2 ± 0.3
15%	62.3 ± 0.6	65.3 ± 0.5	79.3 ± 0.6	95.8 ± 0.2
20%	67.8 ± 0.4	71.6 ± 0.6	85.4 ± 0.6	96.6 ± 0.1
30%	79.7 ± 0.5	83.2 ± 0.0	92.1 v 0.3	97.3 ± 0.1
40%	89.9 v 0.2	90.7 ± 0.3	94.6 ± 0.2	97.8 ± 0.1
50%	96.7 ± 0.2	94.3 ± 0.1	95.9 ± 0.1	98.0 ± 0.1
60%	104.3 ± 0.6	97.0 ± 0.1	97.0 ± 0.1	98.3 ± 0.1
70%	114.5 ± 1.0	102.2 ± 0.1	98.0 ± 0.2	98.5 ± 0.0
80%	126.1 ± 1.9	120.9 ± 0.3	99.5 ± 0.5	98.8 ± 0.1
85%	138.5 ± 0.5	133.2 ± 0.1	101.0 ± 0.3	99.0 ± 0.1
90%	157.4 ± 0.9	151.7 ± 0.4	104.9 ± 1.1	99.4 ± 0.2
95%	167.2 ± 0.7	165.7 ± 0.0	160.3 ± 0.8	100.8 ± 0.3
FBP	193.6 ± 2.6	188.5 ± 0.5	183.1 ± 1.9	107.7 ± 0.3

Table S-7. Experimental D86 distillation temperature measurements for 2-butanol blends with gasoline Values are averages and standard deviations from duplicate or triplicate measurements.

	Temperature (°C)			
	i-Bu10	**i-Bu20**	**i-Bu50**	**i-Bu85**
IBP	31.8 ± 0.4	33.0 ± 0.7	36.9 ± 0.5	52.5 ± 1.6
5%	47.5 ± 0.3	51.4 ± 0.4	60.1 ± 0.6	94.9 ± 0.7
10%	55.7 ± 0.4	59.7 ± 0.1	72.3 ± 0.3	101.1 ± 0.1
15%	61.7 ± 0.0	66.5 ± 0.1	82.0 ± 0.1	103.0 ± 0.1
20%	67.9 ± 0.1	73.2 ± 0.0	89.6 ± 0.2	104.0 ± 0.1
30%	81.1 ± 0.1	86.6 ± 0.2	97.7 ± 0.1	105.2 ± 0.1
40%	92.1 ± 0.1	94.7 ± 0.2	100.7 ± 0.1	105.8 ± 0.0
50%	98.1 ± 0.0	98.1 ± 0.0	102.6 ± 0.1	106.3 ± 0.0
60%	103.1 ± 0.0	100.6 ± 0.3	104.3 ± 0.1	106.5 ± 0.0
70%	112.8 ± 0.2	103.5 ± 0.1	105.8 ± 0.1	106.7 ± 0.1
80%	126.8 ± 0.3	112.7 ± 0.2	107.4 ± 0.2	106.9 ± 0.0
85%	137.7 ± 0.4	131.5 ± 0.4	108.4 ± 0.2	107.0 ± 0.0
90%	157.1 ± 0.1	153.7 ± 0.5	110.0 ± 0.4	107.2 ± 0.0
95%	167.2 ± 0.2	166.4 ± 0.8	115.6 ± 0.2	108.0 ± 0.1
FBP	192.9 ± 0.9	190.7 ± 2.1	158.6 ± 0.5	126.7 ± 0.6

Table S-8. Experimental D86 distillation temperature measurements for *i*-butanol blends with gasoline. Values are averages and standard deviations from duplicate or triplicate measurements.

	Temperature (°C)		
	t-Bu10	**t-Bu20**	**t-Bu50**
IBP	31.3 ± 2.1	33.9 ± 0.6	39.0 ± 0.4
5%	47.4 ± 1.0	50.8 ± 1.0	59.5 ± 0.9
10%	53.8 ± 0.4	56.8 ± 0.7	66.0 ± 0.3
15%	58.5 ± 0.3	61.2 ± 0.4	70.2 ± 0.0
20%	62.7 ± 0.3	65.3 ± 0.2	73.7 ± 0.2
30%	71.9 ± 0.3	73.1 ± 0.2	78.4 ± 0.2
40%	81.9 ± 0.3	79.2 ± 0.2	80.7 ± 0.1
50%	96.1 ± 0.1	84.3 ± 0.4	81.8 ± 0.0
60%	107.3 ± 2.8	92.4 ± 0.4	82.7 ± 0.1
70%	115.7 ± 2.1	112.2 ± 0.5	84.0 ± 0.1
80%	126.8 ± 1.0	122.9 ± 0.8	86.6 ± 0.1
85%	138.5 ± 0.3	132.8 ± 0.4	92.2 ± 0.1
90%	157.6 ± 0.5	152.5 ± 0.9	130.0 ± 0.1
95%	167.8 ± 0.6	166.3 ± 0.2	159.3 ± 0.8
FBP	196.1 ± 1.0	185.4 ± 3.6	180.6 ± 0.1

Table S-9. Experimental D86 distillation temperature measurements for *t*-butanol blends with gasoline. Values are averages and standard deviations from duplicate or triplicate measurements.

	Temperature (°C)						
	Methanol	**1-Propanol**	**2-Propanol**	**1-Butanol**	**2-Butanol**	***i*-Butanol**	***t*-Butanol**
IBP	33.5 ± 0.3	33.1 ± 0.5	33.0 ± 1.1	34.2 ± 0.7	32.7 ± 1.0	33.1 ± 0.2	33.5 ± 0.1
5%	46.1 ± 0.3	47.8 ± 1.5	48.3 ± 0.9	50.1 ± 0.1	47.0 ± 0.5	47.5 ± 1.0	48.6 ± 0.4
10%	49.6 ± 0.1	53.9 ± 1.1	53.7 ± 0.5	55.7 ± 0.0	53.4 ± 0.3	53.6 ± 0.8	54.0 ± 0.4
15%	52.6 ± 0.3	58.6 ± 0.8	57.8 ± 0.3	59.8 ± 0.1	58.1 ± 0.4	58.2 ± 0.6	58.3 ± 0.1
20%	55.7 ± 0.1	63.2 ± 0.6	61.7 ± 0.1	64.4 ± 0.1	62.7 ± 0.2	62.9 ± 0.4	62.4 ± 0.1
30%	61.1 ± 0.1	71.8 ± 0.3	68.8 ± 0.2	73.9 ± 0.1	71.2 ± 0.1	71.9 ± 0.4	69.4 ± 0.1
40%	65.6 ± 0.0	78.6 ± 0.1	73.5 ± 0.2	82.7 ± 0.1	78.7 ± 0.0	80.3 ± 0.2	75.0 ± 0.1
50%	69.9 ± 0.1	83.2 ± 0.1	76.9 ± 0.3	94.2 ± 0.1	85.4 ± 0.8	89.0 ± 0.1	79.2 ± 0.3
60%	82.2 ± 0.6	89.0 ± 0.1	81.7 ± 0.5	103.3 ± 0.0	94.2 ± 0.6	97.5 ± 0.4	88.7 ± 0.6
70%	114.4 ± 0.1	99.9 ± 0.5	111.9 ± 0.7	108.1 ± 0.2	104.9 ± 0.6	105.0 ± 0.4	112.5 ± 0.8
80%	124.5 ± 0.0	124.1 ± 0.2	124.1 ± 0.3	116.7 ± 0.0	123.2 ± 0.3	120.8 ± 0.4	124.2 ± 0.2
85%	134.7 ± 0.0	134.2 ± 0.5	133.7 ± 0.5	130.8 ± 0.4	133.6 ± 0.1	134.1 ± 0.1	134.2 ± 0.1
90%	154.8 ± 0.2	152.9 ± 1.1	153.1 ± 0.9	153.8 ± 0.4	152.2 ± 0.2	152.7 ± 0.6	152.5 ± 0.1
95%	166.5 ± 0.1	166.2 ± 0.3	166.0 ± 0.5	166.3 ± 0.1	166.1 ± 0.3	166.3 ± 0.1	166.0 ± 0.0
FBP	194.9 ± 0.0	194.6 ± 0.4	189.7 ± 0.6	190.0 ± 4.2	192.4 ± 0.7	191.2 ± 0.6	191.7 ± 4.5

Table S-10. Experimental D86 distillation temperature measurements for dual-alcohol blends containing 10% v/v ethanol, 10% v/v of another alcohol (as listed in the table) and 80% v/v gasoline. Values are averages and standard deviations from duplicate or triplicate measurements.

	Temperature (°C)		
	10% Methanol + 10% 2-Propanol	**10% Methanol + 10% 1-Butanol**	**10% 2-Propanol + 10% 1-Butanol**
IBP	33.3 ± 0.5	33.3 ± 0.3	33.1 ± 0.2
5%	44.9 ± 0.2	44.1 ± 0.2	49.7 ± 0.1
10%	48.6 ± 0.1	47.5 ± 0.2	56.7 ± 0.1
15%	52.0 ± 0.1	51.1 ± 0.2	61.9 ± 0.1
20%	55.1 ± 0.0	54.6 ± 0.2	67.0 ± 0.1
30%	61.2 ± 0.0	59.7 ± 1.9	77.5 ± 0.2
40%	67.0 ± 0.1	74.4 ± 0.1	86.7 ± 0.3
50%	73.3 ± 0.1	97.9 ± 0.5	94.1 ± 0.1
60%	86.8 ± 0.1	104.1 ± 0.5	101.3 ± 0.1
70%	112.8 ± 0.2	108.5 ± 0.1	107.3 ± 0.2
80%	123.5 ± 0.0	117.3 ± 0.1	116.2 ± 0.1
85%	133.2 ± 0.2	131.7 ± 0.1	129.9 ± 0.2
90%	153.2 ± 0.3	154.0 ± 0.3	153.0 ± 0.2
95%	166.3 ± 0.1	166.4 ± 0.2	166.2 ± 0.1
FBP	189.5 ± 4.0	193.3 ± 0.9	190.8 ± 0.4

Table S-11. Experimental D86 distillation temperature measurements for 10% v/v each of two alcohols (as listed in the table) and 80% v/v gasoline. Values are averages and standard deviations from duplicate or triplicate measurements.

S.3 Additional Figures

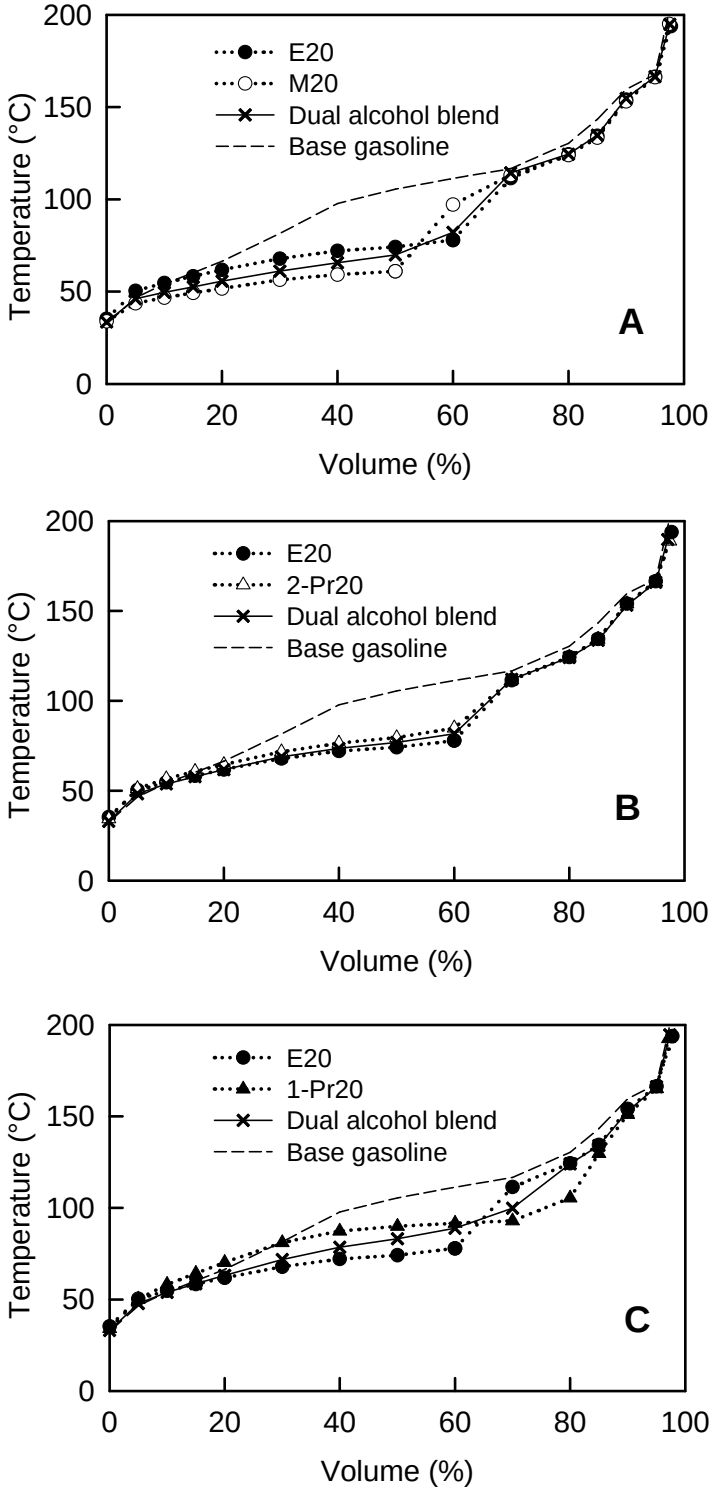

Figure S-2. Distillation curves for dual-alcohol blends containing 10% v/v ethanol, 10% v/v of a second alcohol (methanol, 1-propanol or 2-propanol) and 80% v/v gasoline.

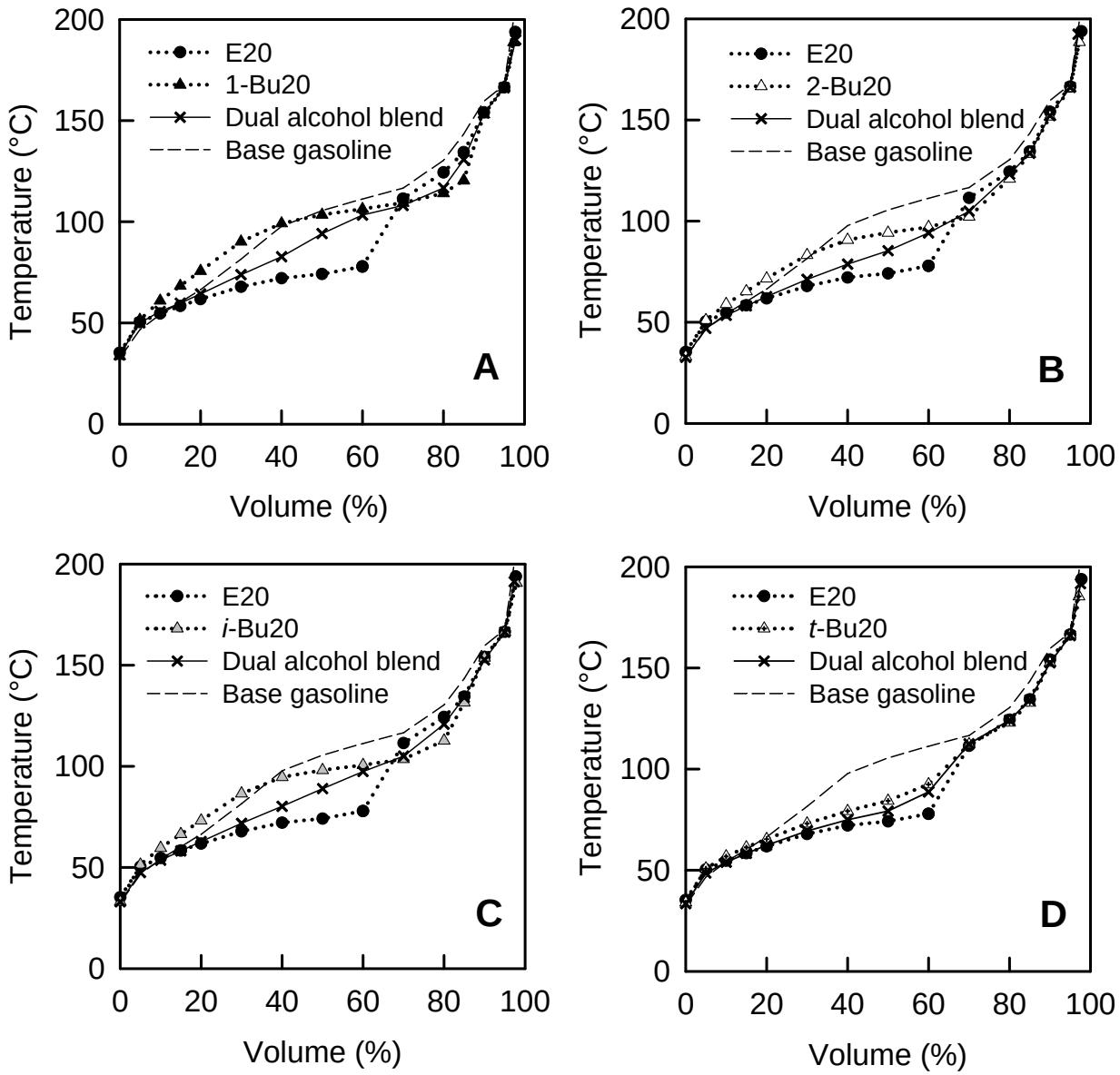

Figure S-3. Distillation curves for dual alcohol blends containing 10% v/v ethanol, 10% v/v of one of the butanol isomers, and 80% v/v gasoline.

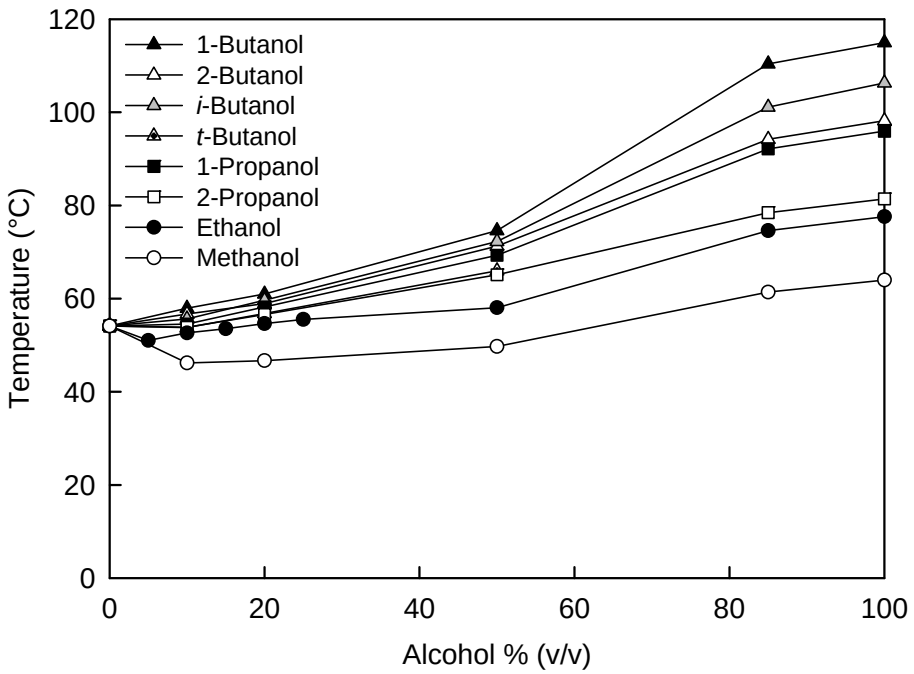

Figure S-4. T10 values of the alcohol blends as a function of alcohol content.

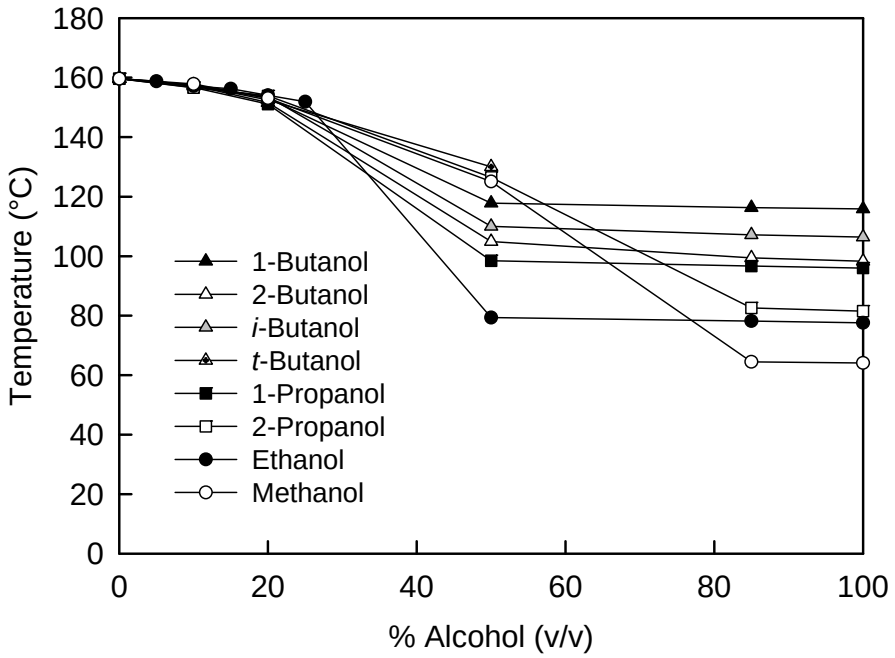

Figure S-5. T90 values of the alcohol blends as a function of alcohol content.