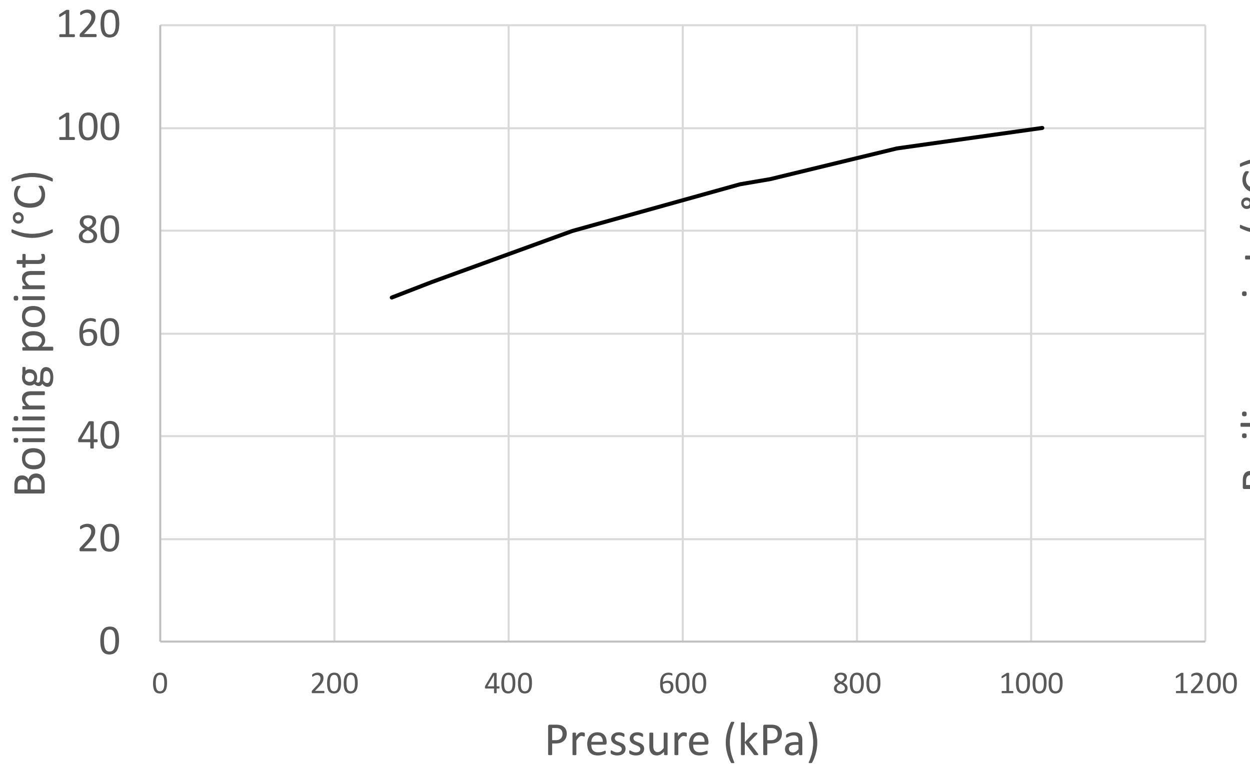
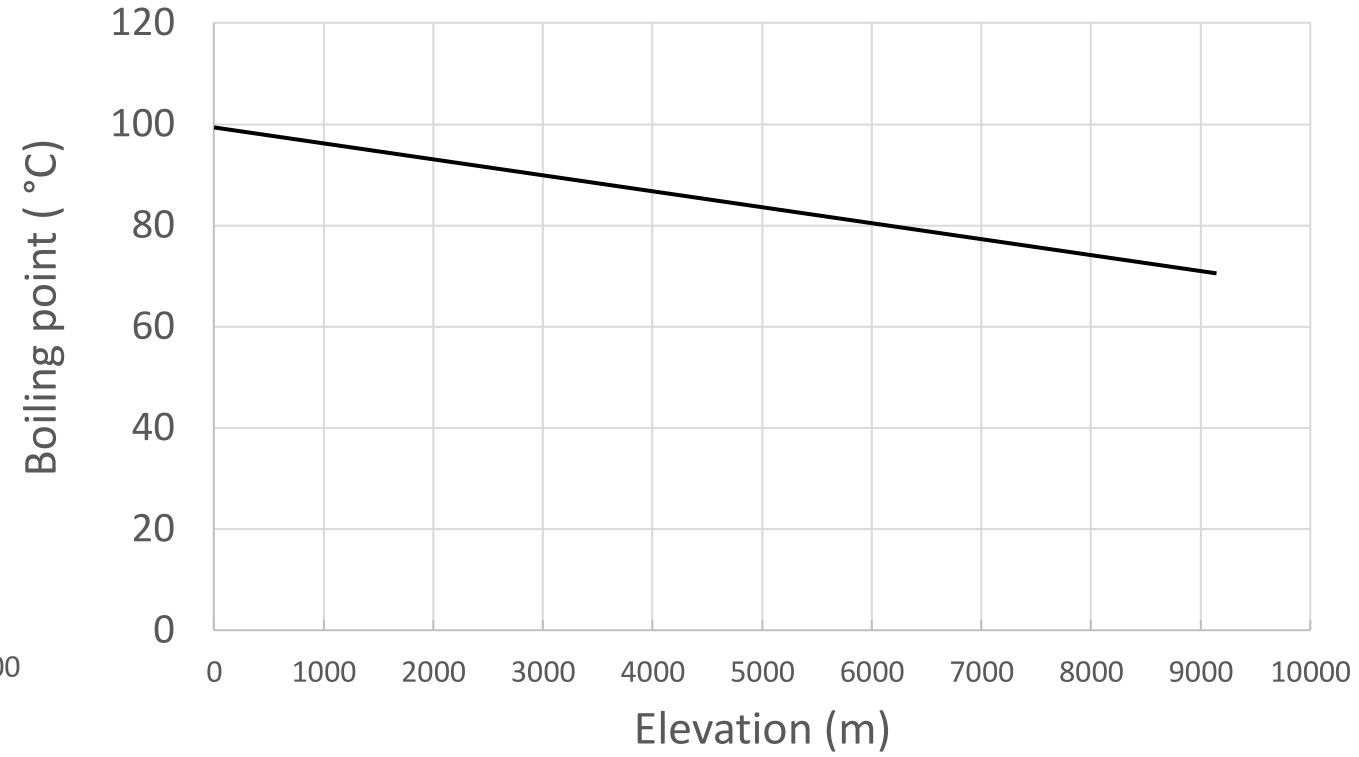
MASSEY UNIVERSITY

280.371 Process Engineering Operations

Evaporation Lecture 3

Professor Marie Wong





Mount Everest
8848 m

Aoraki/ Mount Cook
3724 m

Mount Kinabalu
4095 m

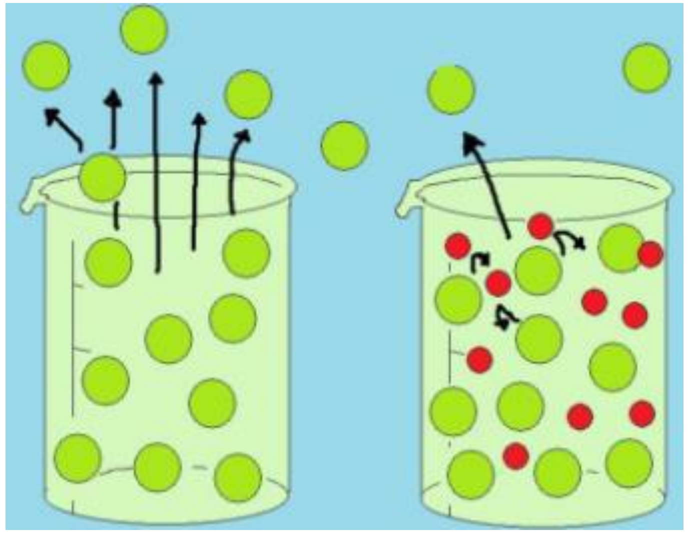
Massey University
STEAM TABLES

3 Saturated Data

P	θ_{sat}	v_l	v_v	u_l	u_v	h_l	$\Delta(h_{vap})$	h_v	s_l	s_v
MPa	°C	m^3/Mg		kJ/kg		kJ/kg			kJ/(kgK)	
0.0010	6.970	1.000	129178	29.30	2384	29.30	2484	2514	0.106	8.975
0.0015	13.02	1.001	87959	54.68	2393	54.68	2470	2525	0.196	8.827
0.0020	17.49	1.001	66987	73.43	2399	73.43	2459	2533	0.261	8.723
0.0025	21.08	1.002	54240	88.42	2404	88.42	2451	2539	0.312	8.642
0.0030	24.08	1.003	45653	101.0	2408	101.0	2444	2545	0.354	8.576
0.0035	26.67	1.003	39466	111.8	2411	111.8	2438	2550	0.391	8.521
0.0040	28.96	1.004	34791	121.4	2415	121.4	2432	2554	0.422	8.473
0.0045	31.01	1.005	31131	130.0	2417	130.0	2427	2557	0.451	8.431
0.0050	32.87	1.005	28185	137.7	2420	137.7	2423	2561	0.476	8.394
0.0060	36.16	1.006	23733	151.5	2424	151.5	2415	2567	0.521	8.329
0.0070	39.00	1.008	20524	163.3	2428	163.4	2408	2572	0.559	8.274
0.0080	41.51	1.008	18099	173.8	2431	173.8	2402	2576	0.592	8.227
0.0090	43.76	1.009	16199	183.2	2434	183.3	2397	2580	0.622	8.186
0.010	45.81	1.010	14670	191.8	2437	191.8	2392	2584	0.649	8.149
0.011	47.68	1.011	13412	199.6	2440	199.7	2388	2587	0.674	8.115

Add sugar
boiling point
changes

Colligative property
- boiling point elevation

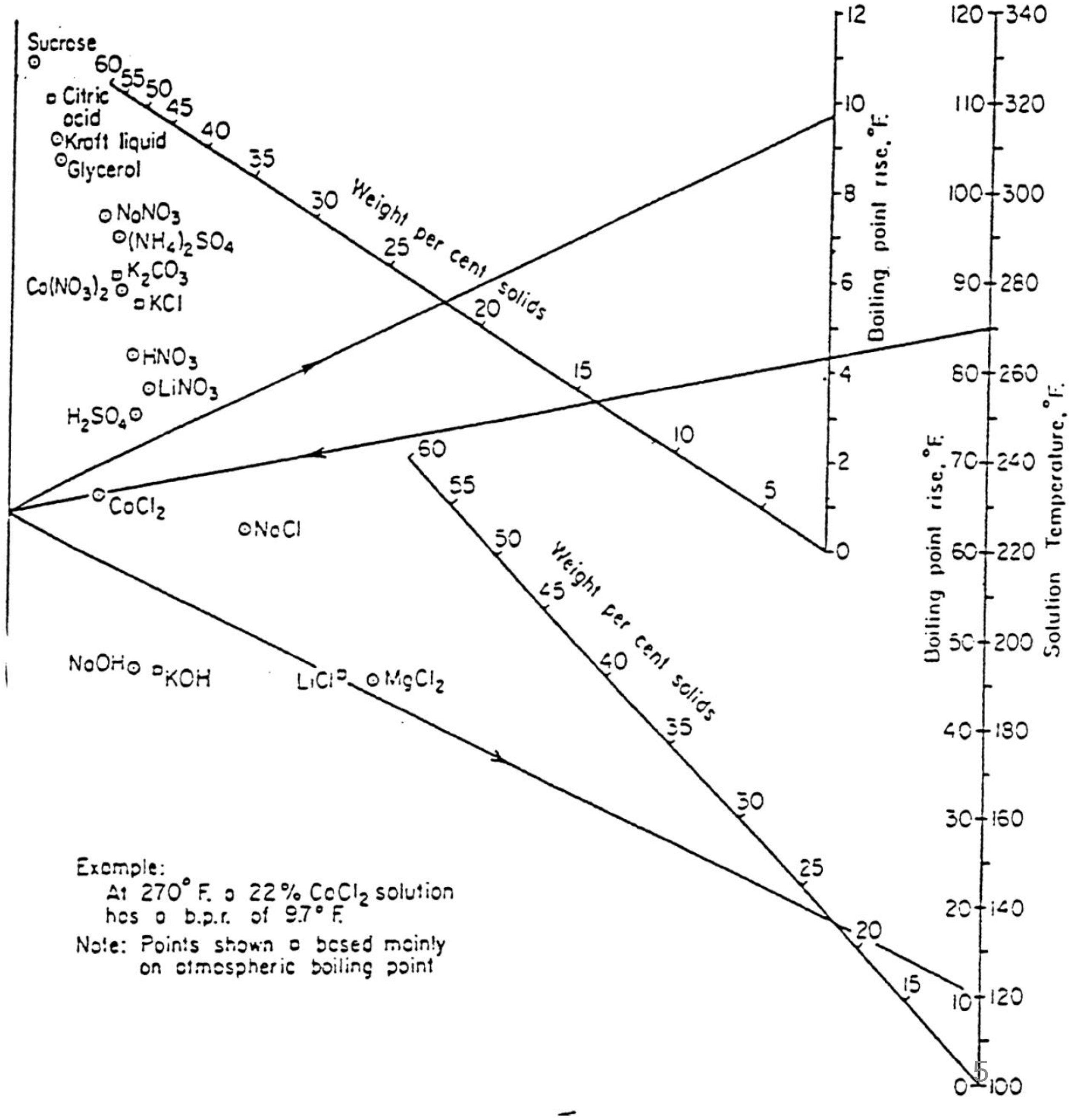


Pure solvent Solvent + solute

Boiling point Elevation Dühring Chart

Calculate boiling point change

Boiling point Elevation Dühring Chart



Boiling Point Rise (BPR)

- a.k.a. boiling point elevation (BPE)
- Can be significant in concentrated solutions
- Important for when sizing an evaporator

Impact of BPR

- Key effect of BPR is to decrease available $\Delta\theta$ (temperature driving force)

- BPR increases with increasing concentration
  - BPR reduces driving force for ϕ
  - ϕ determined by throughput and degree of concentration required
  - Viscosity also increases with concentration and acts to reduce U
  - To achieve constant ϕ, assuming A is constant, $\Delta\theta$ will need to increase at high solution concentrations

Converting between ºF and ºC

Absolute temperatures

$$°C = (°F - 32) \times \frac{5}{9}$$

$$°C = \frac{(°F - 32)}{1.8}$$

$$°F = \left(°C \times \frac{9}{5}\right) + 32$$

$$°F = (°C \times 1.8) + 32$$

A temperature difference $\Delta\theta$

$$\Delta\theta°C = (\Delta\theta°F) \times \frac{5}{9}$$

$$°C = \frac{(\Delta\theta°F)}{1.8}$$

$$\Delta\theta°F = \left(\Delta\theta°C \times \frac{9}{5}\right)$$

$$\Delta\theta°F = (\Delta\theta°C \times 1.8)$$

How to find BPR

- Pure compounds boil at a constant temperature:

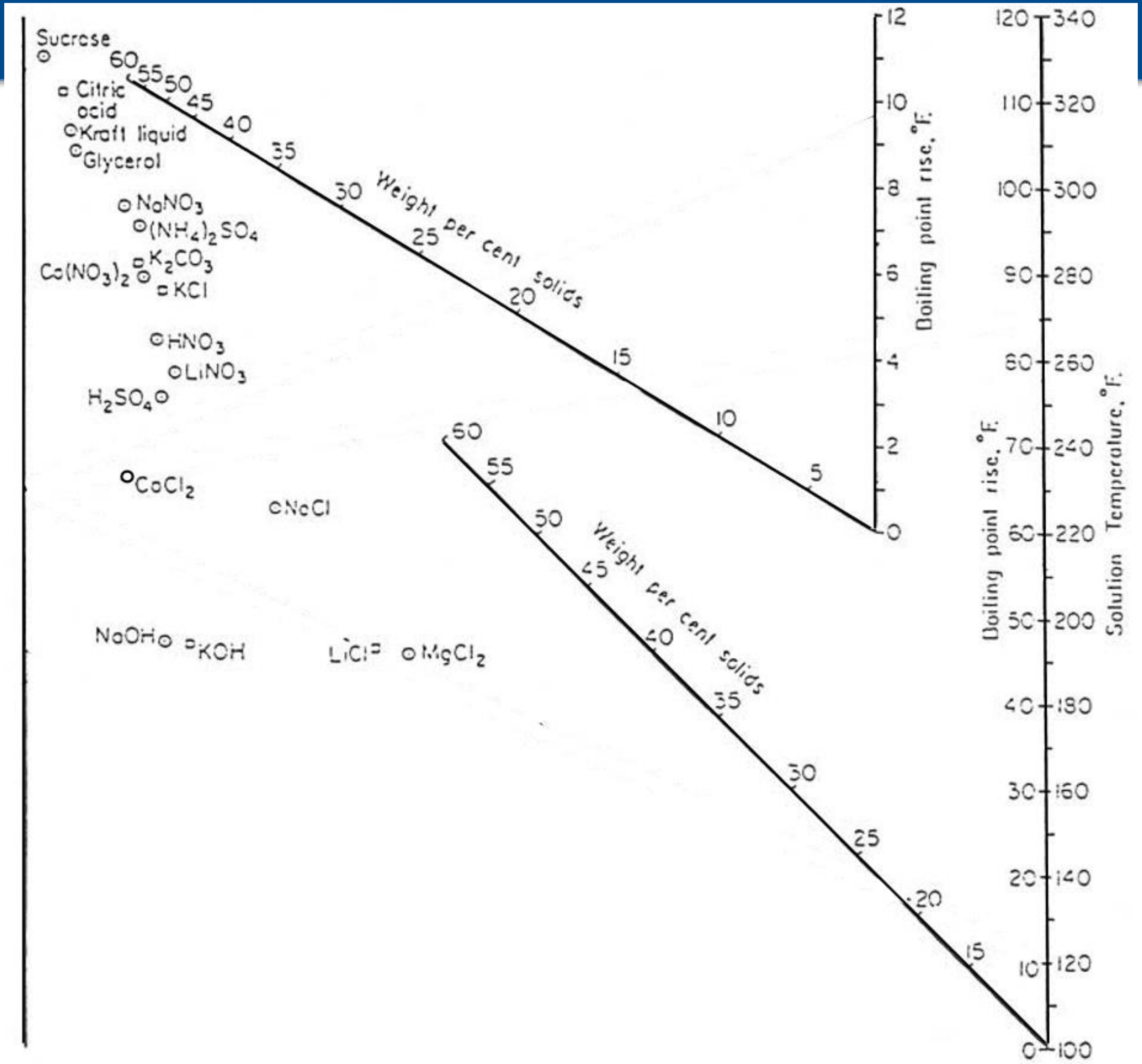
  θ_{sat} or θ_{pure}

- Vapour pressure above a solution is reduced, so for given pressure, solution boiling point is higher than for solvent

  $$\theta_{soln} > \theta_{pure}$$

- Dühring charts commonly used to give θ_{soln}

Dühring chart



Solution Temperature and Enthalpy with BPR

- θ_{soln} is given by

$$\theta_{soln} = \theta_{pure} + \Delta\theta_{BPR}$$

- The solution enthalpy is calculated

$$h_{soln} = c_{p_{soln}}\left(\theta_{soln} - \theta_{ref}\right)$$

Enthalpy of vapour and BPR

- Vapour evaporating from a solution leaves at $\theta_{soln} > \theta_{pure}$, , i.e. vapour is superheated

$$h_V = h_{V_{sat}} + c_{p_V}\left(\Delta\theta_{BPR}\right)$$

Enthalpy of liquid

Latent heat of evaporation = h_{fg}

Enthalpy of vapour = h_v

3 Saturated Data

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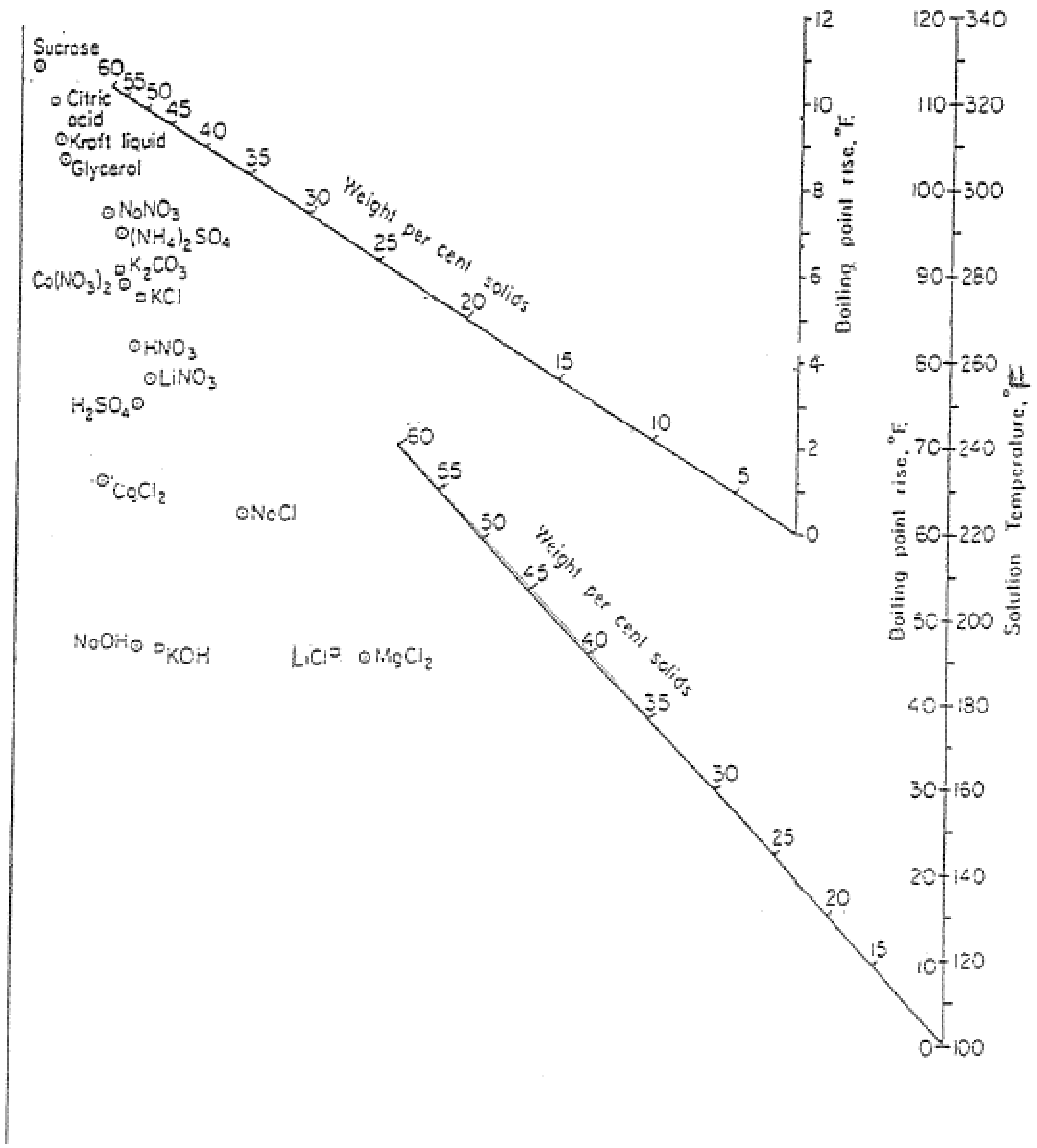
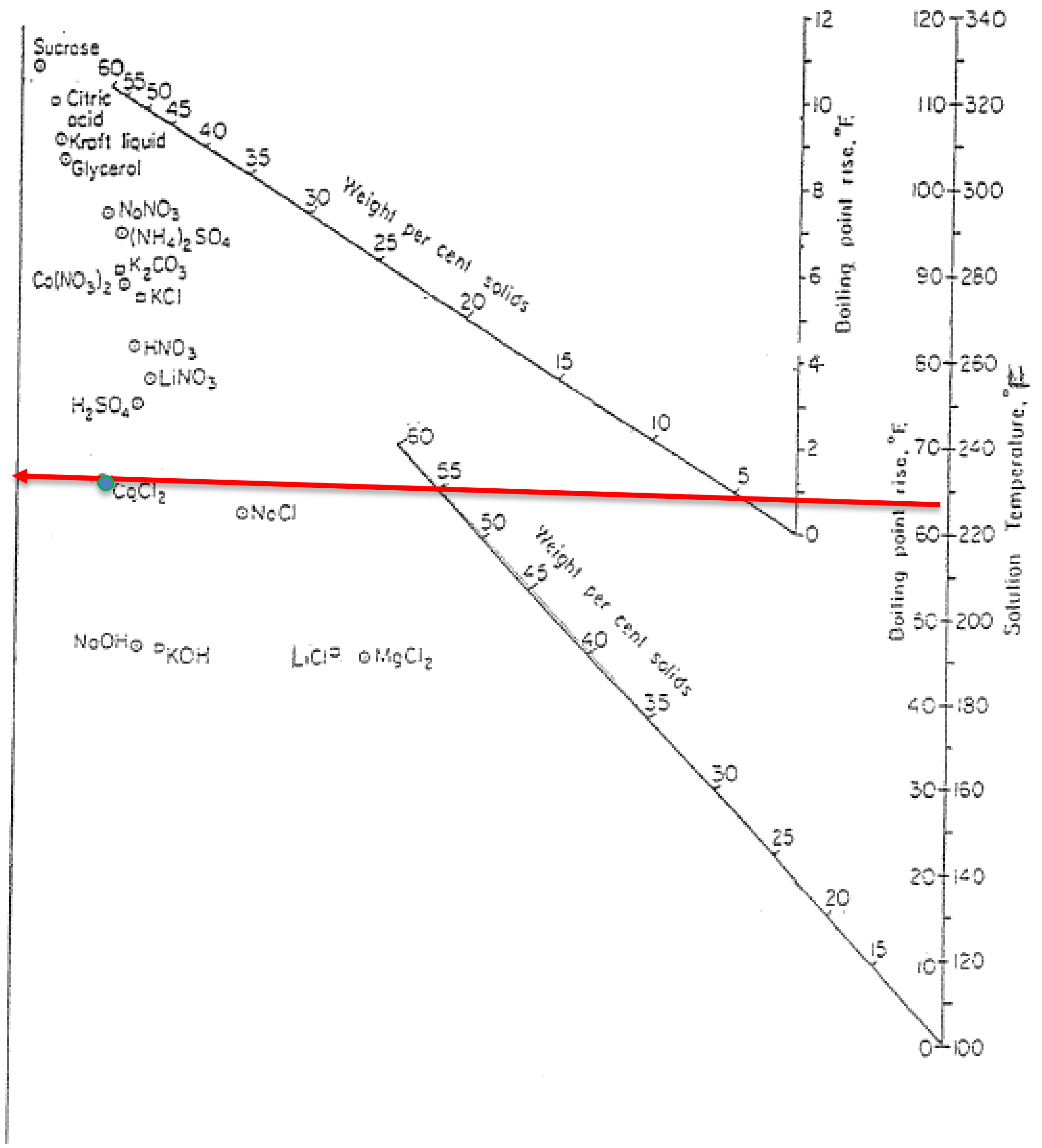
0.011	47.68	1.011	13412	199.6	2440	199.7	2388	2587	0.674	8.115
0.012	49.42	1.012	12358	206.9	2442	206.9	2383	2590	0.696	8.085
0.013	51.03	1.013	11462	213.7	2444	213.7	2379	2593	0.717	8.057
0.014	52.55	1.013	10691	220.0	2446	220.0	2376	2596	0.737	8.031
0.015	53.97	1.014	10020	225.9	2448	225.9	2372	2598	0.755	8.007
0.016	55.31	1.015	9431	231.5	2450	231.6	2369	2601	0.772	7.985
0.018	57.80	1.016	8443	241.9	2453	242.0	2363	2605	0.804	7.944
0.020	60.06	1.017	7648	251.4	2456	251.4	2358	2609	0.832	7.907
0.022	62.13	1.018	6994	260.1	2459	260.1	2352	2613	0.858	7.874

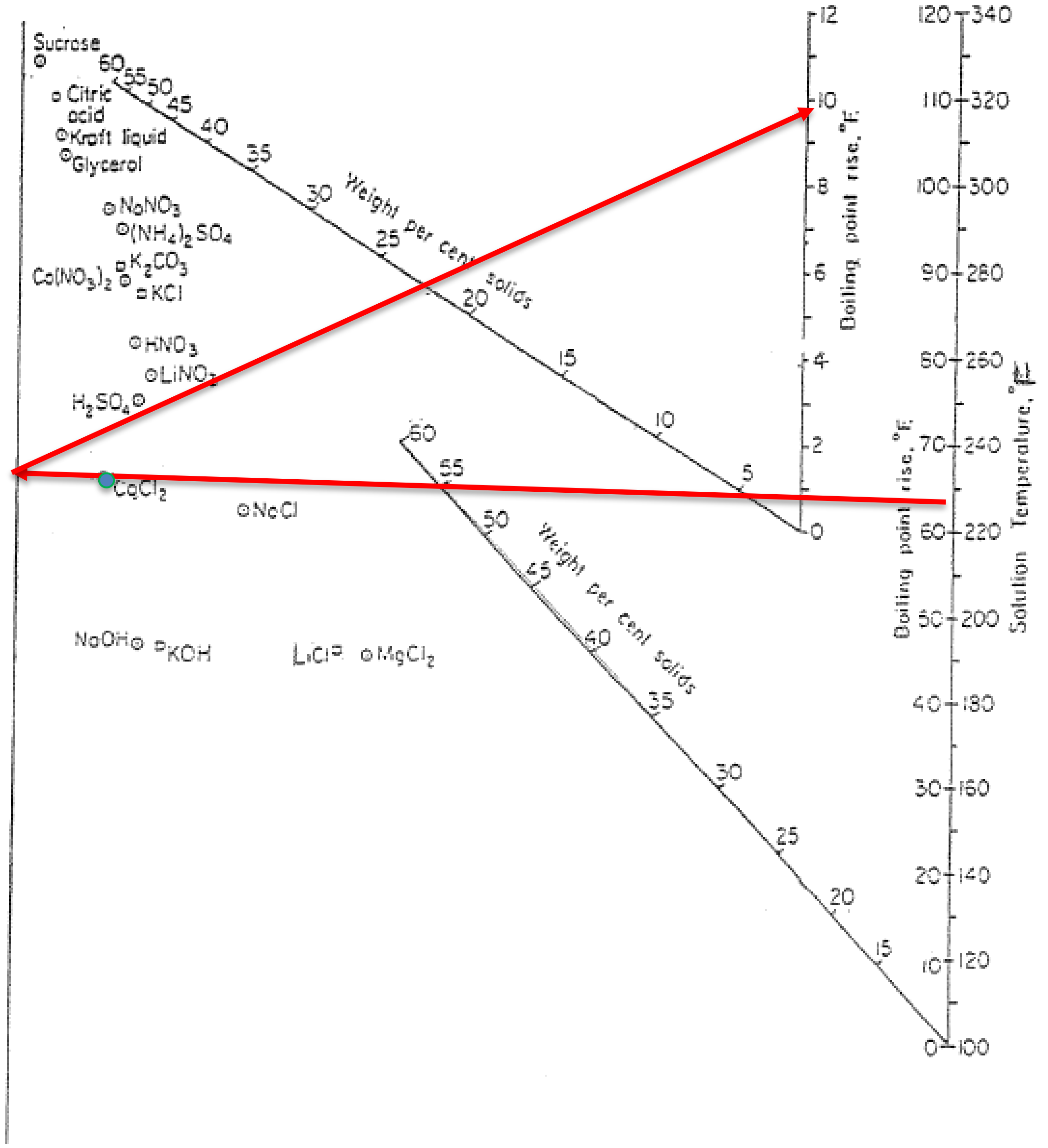
Procedure to estimate BPR

1. Determine the pure component boiling point
2. Assume a boiling point rise
3. Calculate the solution temperature
4. Use the chart to obtain the boiling point rise for that solution temperature
5. Compare the assumed boiling point rise with that obtained from the graph. If not the same assume a new boiling point rise and return to step 3

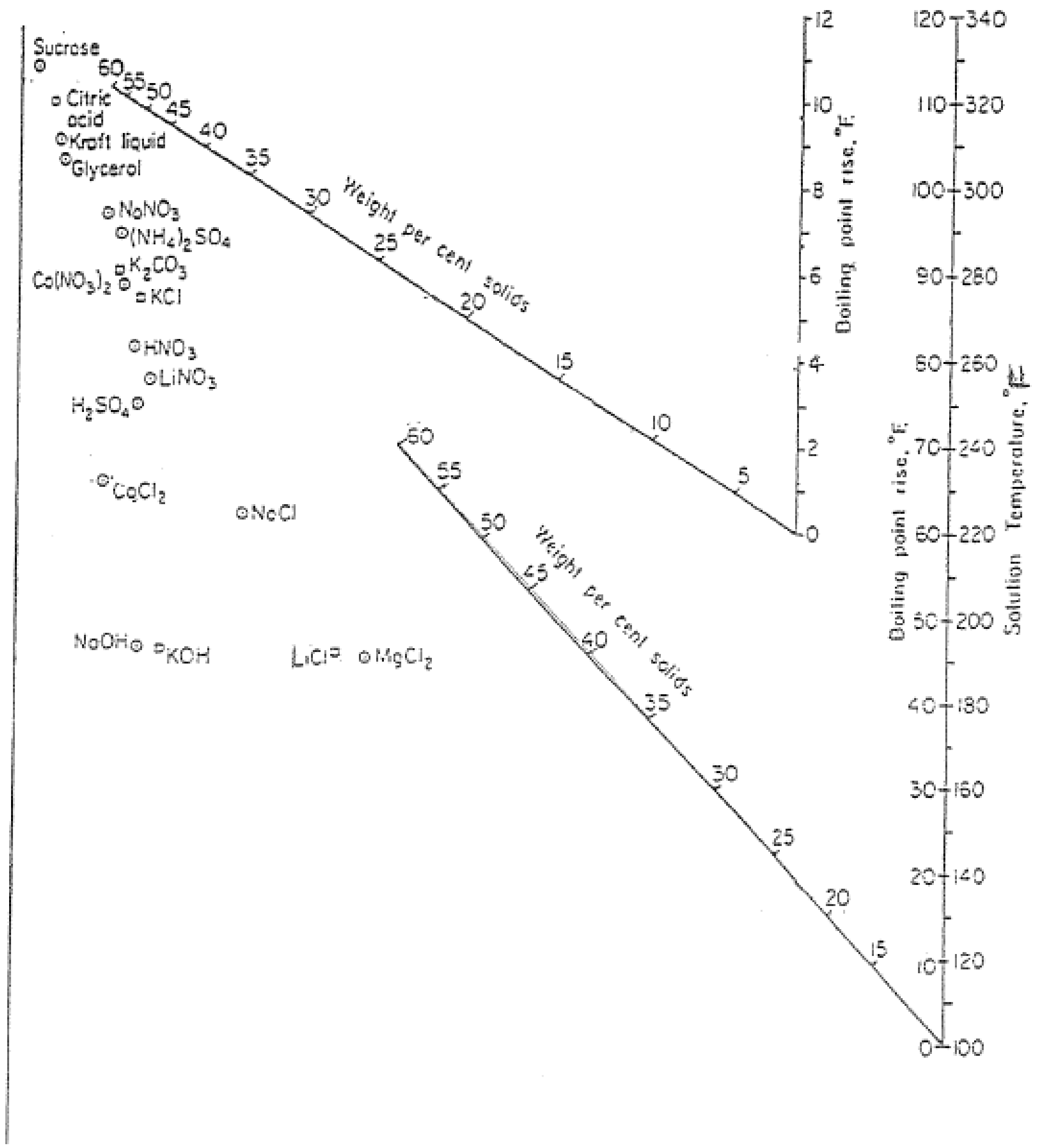
Example: At 270 ºF , a 22 wt% calcium chloride solution has a boiling point rise of 9.7ºF.




Sucrose
Citric acid
Kraft liquid
Glycerol
$NaNO_3$
$(NH_4)_2SO_4$
K_2CO_3
$Ca(NO_3)_2$
KCl
HNO_3
$LiNO_3$
H_2SO_4
$CaCl_2$
NaCl
NaOH
KOH
LiCl
$MgCl_2$
Weight per cent solids
Weight per cent solids
Boiling point rise, °F
Boiling point rise, °F
Solution Temperature, °F



Sucrose
Citric acid
Kraft liquid
Glycerol
$NaNO_3$
$(NH_4)_2SO_4$
K_2CO_3
$Ca(NO_3)_2$
KCl
HNO_3
$LiNO_3$
H_2SO_4
$CaCl_2$
NaCl
NaOH
KOH
LiCl
$MgCl_2$
Weight per cent solids
Weight per cent solids
Boiling point rise, °F
Boiling point rise, °F
Solution Temperature, °F



Sucrose
Citric acid
Kraft liquid
Glycerol
NaNO3
(NH4)2SO4
K2CO3
Ca(NO3)2
KCl
HNO3
LiNO3
H2SO4
CaCl2
NaCl
NaOH
KOH
LiCl
MgCl2
Weight per cent solids
Weight per cent solids
Boiling point rise, °F
Boiling point rise, °F
Solution Temperature, °F

Boiling point elevation: Iterative Solution Procedure (for calculating solution temperature from solute conc)

Step 1. Determine the pure component boiling point

Step 2. Assume a boiling point rise

Step 3. Calculate the solution temperature

Step 4. Use the chart to obtain the boiling point rise for that solution temperature

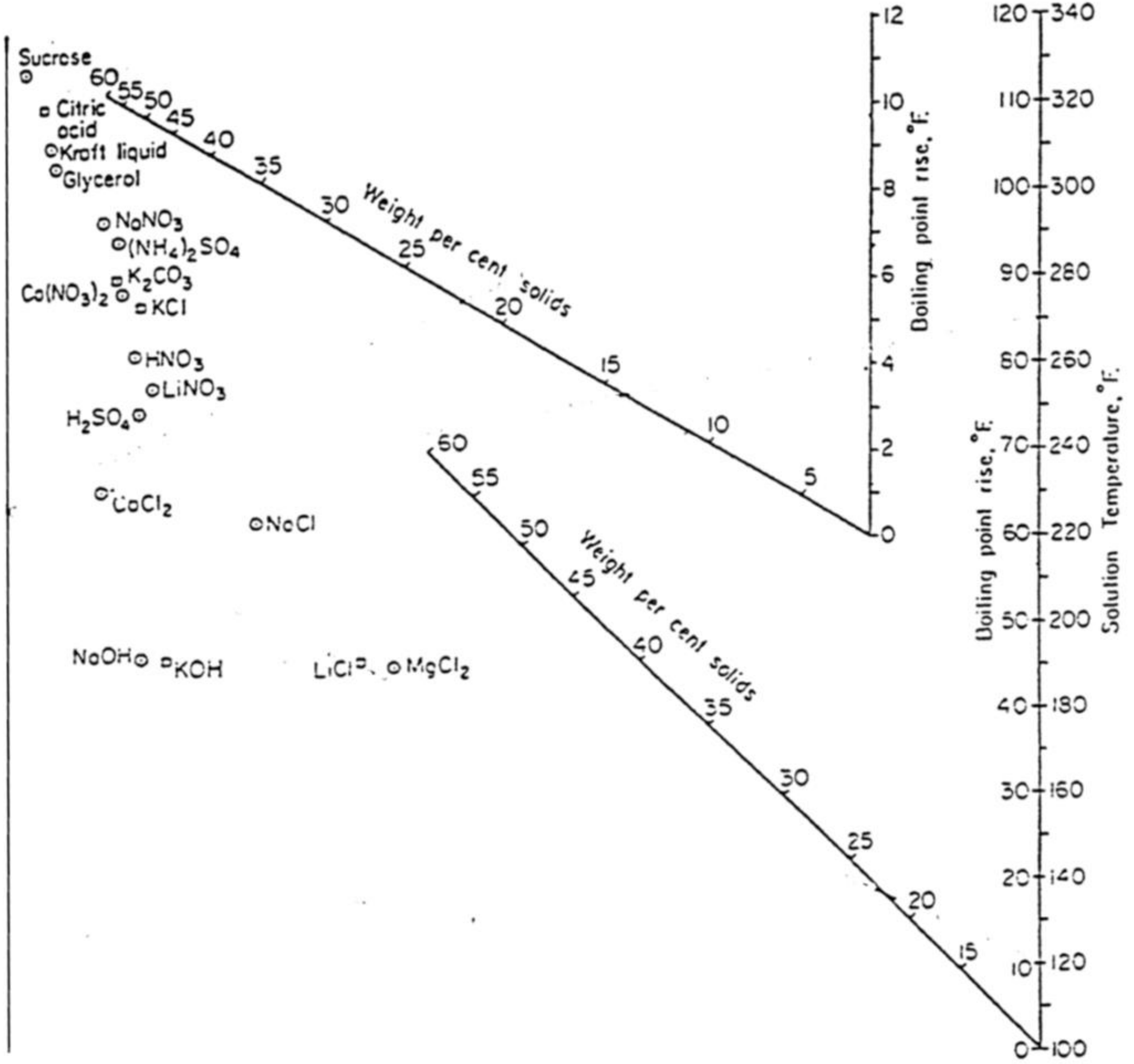
Step 5. Compare the assumed boiling point rise with that obtained from the graph. If not the same assume a new boiling point rise and return to step 3

Question 4: Using the chart and steam tables (not iterative)

(a) What concentration of NaCl is required to give a boiling point rise of 9°F at atmospheric pressure ?

(b) What will be

- The solution temperature?
- The vapour enthalpy (c_{pg} = 1.88 kJ/kg°C)?
- The liquid enthalpy assuming that the specific heat of the salt solution is 4 kJ/kg°C?


Sucrose
Citric acid
Kraft liquid
Glycerol
NaNO3
(NH4)2SO4
K2CO3
Ca(NO3)2
KCl
HNO3
LiNO3
H2SO4
CaCl2
NaCl
NaOH
KOH
LiCl
MgCl2
Weight per cent solids
Weight per cent solids
Boiling point rise, °F.
Boiling point rise, °F.
Solution Temperature, °F.
0
5
10
15
20
25
30
35
40
45
50
55
60
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80
90
100
110
120
100
120
140
160
180
200
220
240
260
280
300
320
340

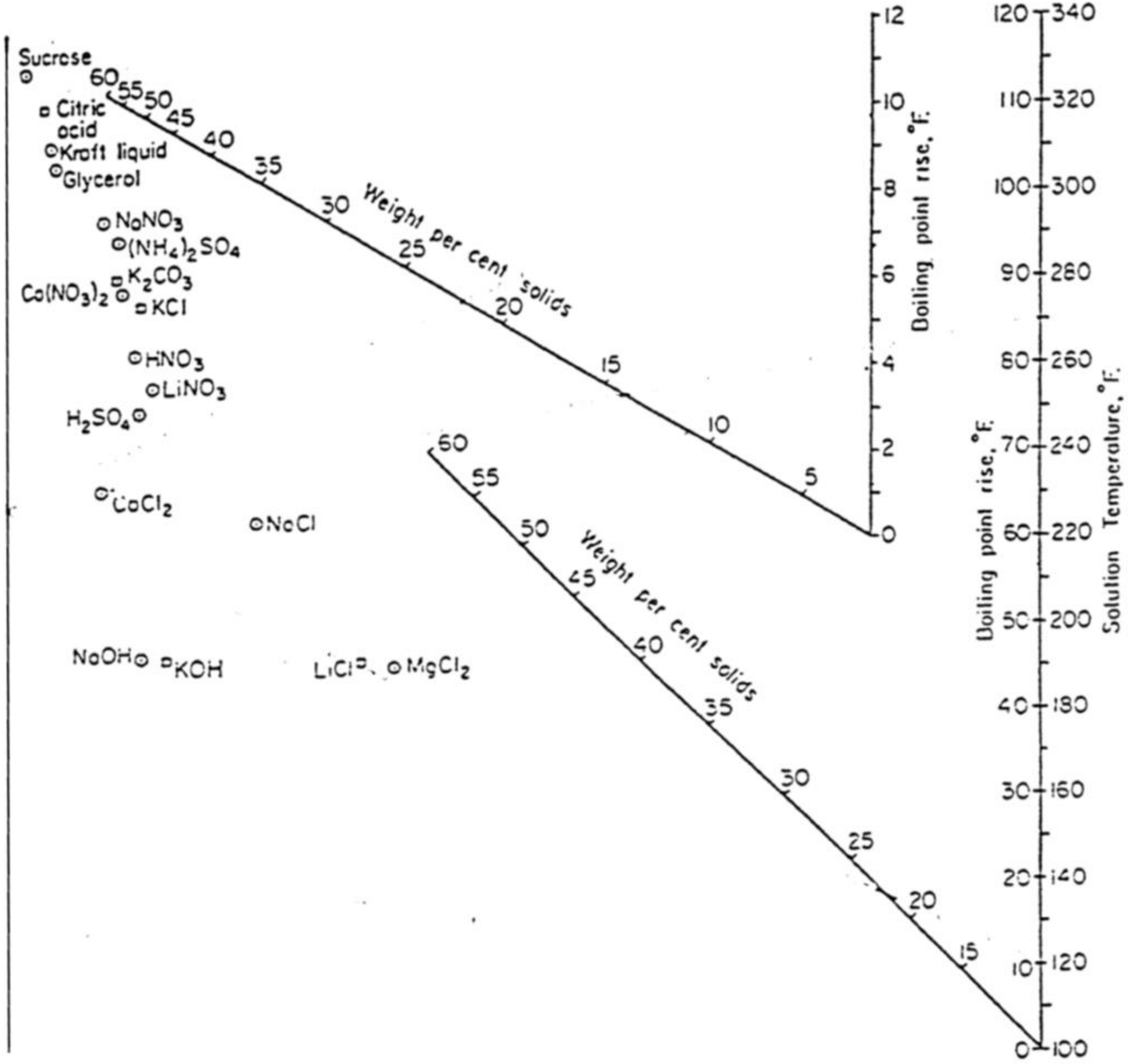
°F

Question 5: Using the chart and steam tables (iterative).

(a) What is the solution boiling point of 40wt% LiCl solution at 50 kPa absolute.

(b) What will be

- The boiling point rise?
- The vapour enthalpy (c_{pg} = 1.88 kJ/kg°C)?
- The liquid enthalpy assuming that the specific heat of the salt solution is 3.5 kJ/kg°C?



Sucrose
Citric acid
Kraft liquid
Glycerol
NaNO3
(NH4)2SO4
K2CO3
Ca(NO3)2
KCl
HNO3
LiNO3
H2SO4
CaCl2
NaCl
NaOH
KOH
LiCl
MgCl2
Weight per cent solids
Weight per cent solids
Boiling point rise, °F.
Boiling point rise, °F.
Solution Temperature, °F.

°F