

# Extraction optimization of organic compounds by demixing observed in the H<sub>2</sub>O–NaOH–piperidine ternary diagram

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**Abstract** Three isothermal sections of the isobaric ternary system H<sub>2</sub>O–NaOH–C<sub>5</sub>H<sub>10</sub>NH were determined by Isoplethic Thermal Analysis at 293, 313, and 323 K. Miscibility gaps were completely delimited and each critical point was calculated. This system is then characterized by a prevalent miscibility gap, three crystallization domains and two triphasic invariant domains. The relevant exploitation of this diagram so permits us to deduce the demixing temperature leading to the optimal transfer of the organic compounds in the light phase and also the composition of the organic phase recovered after this second step of extraction. Moreover, the addition of calculated quantities of sodium hydroxide aqueous solution allows to be in optimized conditions for the next distillation operations.

**Keywords** Ternary diagram · Isoplethic thermal analysis · Miscibility gap · Critical point · Piperidine · Water · Sodium hydroxide · Extraction

## Introduction

The *N*-aminopiperidine, hydrazine of great interest, is often used in pharmaceutical applications. It is produced by reaction between the hydroxylamine-*O*-sulfonic acid and a

large excess of piperidine (C<sub>5</sub>H<sub>10</sub>NH). Our laboratory studies its extraction process in conformity with the particularly restricting specifications.

The first step consists to neutralize the piperidine salt of the crude synthesis solutions by soda addition. A demixing phenomenon appears due to the desiccant power of the sodium sulfate thus produced. The optimization of this step required then the study of the polythermal ternary system H<sub>2</sub>O–Na<sub>2</sub>SO<sub>4</sub>–C<sub>5</sub>H<sub>10</sub>NH [1, 2].

The organic liquid obtained from the first demixing is then treated by soda. This second step consists in concentrating hydrazine and excess piperidine for the next distillation operations. But this recovered phase being composed of piperidine and water; and knowing that *N*-aminopiperidine has similar organic properties to piperidine, we considered so that the amine controls the demixing phenomenon by solvent effect. The optimization of this step requires then the study of the ternary system H<sub>2</sub>O–NaOH–C<sub>5</sub>H<sub>10</sub>NH.

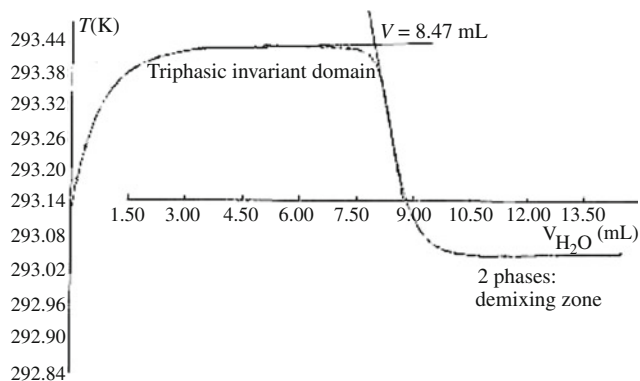
## Experimental

Piperidine (99%) and sodium hydroxide were obtained from Acros. All chemicals were used without any further purification and double distilled, deionised water was used.

Three isothermal sections of the ternary system H<sub>2</sub>O–NaOH–C<sub>5</sub>H<sub>10</sub>NH were determined at atmospheric pressure by Isoplethic Thermal Analysis [1–3] (ITA) at 293, 313, and 323 K. ITA is a synthetic method of isobaric thermal analysis. Its principle is based on the measurement of the thermal effects linked to the system transformations (phase appearance or disappearance), when its composition is modified. The mixture is maintained under quasi-isothermal conditions and the temperature variations, about

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**Fig. 1** Curve obtained by ITA

some hundredths of degree, are represented according to the global composition of the system. ITA was used to delimit the various equilibrium domains.

The sample is composed of three compounds, piperidine, water and sodium hydroxide. The composition of this ternary mixture is initially located in the three-phase invariant domain, so we can observe two liquid phases and a solid one. When it reaches the working temperature, water is added. The variation of the temperature  $\Delta T$  is recorded as a function of the volume  $v$  of water added. Each equilibrium domain has a corresponding specific variation law, and each break in this variation corresponds to a change in the number or the nature of the phases in equilibrium. Figure 1 shows a curve obtained by ITA.

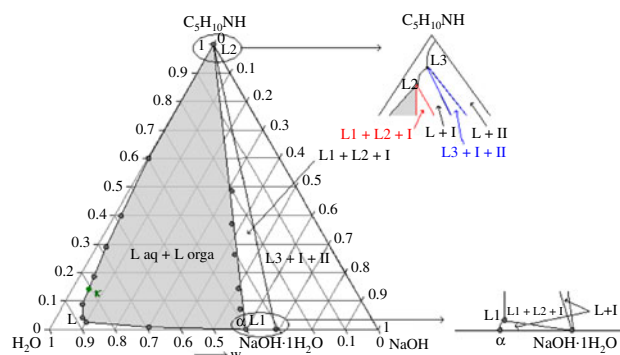
The initial temperature of the sample was 293.14 K. There is an exothermic phenomenon when the first drops of water are added, and then we can observe a plateau of invariance. We can see an endothermic phenomenon which corresponds to a change of domain after 8.47 mL of water added (solubilization of the solid phase).

## Results

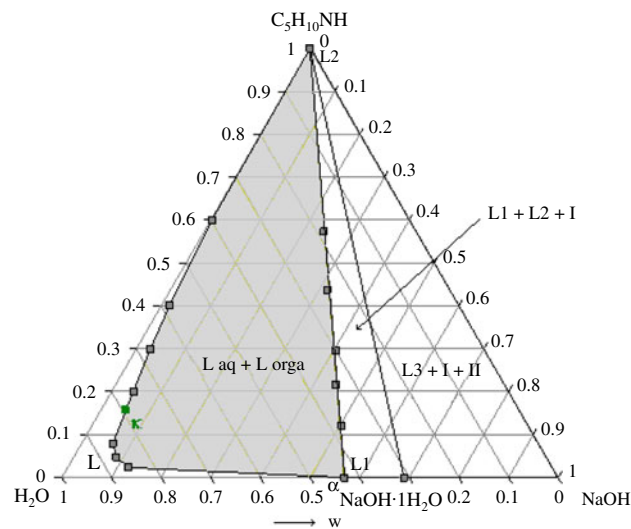
Figures 2, 3, and 4 represent, respectively, the isobaric isotherms 323, 313, and 293 K of the ternary system  $\text{H}_2\text{O}-\text{NaOH}-\text{C}_5\text{H}_{10}\text{NH}$  and Tables 1, 2, and 3 collect the associated experimental compositions, expressed in mass fractions.

The ternary system is delimited by three binary systems. The  $\text{NaOH}-\text{C}_5\text{H}_{10}\text{NH}$  system is unknown. In the temperature field studied, piperidine is totally miscible in water and soda is present as anhydrous and monohydrated forms [4–6].

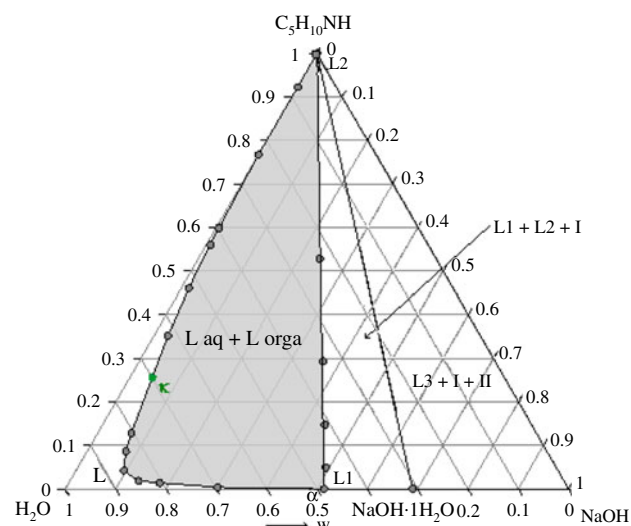
The compositions of the invariant liquids L1 were obtained by acidimetric titration and those of the critical point  $\kappa$  of the miscibility gap by the generalized diameter method [1]. The organic liquids L2 and L3 were not determined.



**Fig. 2** Ternary system  $\text{H}_2\text{O}-\text{NaOH}-\text{C}_5\text{H}_{10}\text{NH}$ : isotherm 323 K ( $P = 1$  bar). I:  $\text{NaOH}\cdot\text{H}_2\text{O}$ ; II:  $\text{NaOH}$



**Fig. 3** Ternary system  $\text{H}_2\text{O}-\text{NaOH}-\text{C}_5\text{H}_{10}\text{NH}$ : isotherm 313 K ( $P = 1$  bar). I:  $\text{NaOH}\cdot\text{H}_2\text{O}$ ; II:  $\text{NaOH}$



**Fig. 4** Ternary system  $\text{H}_2\text{O}-\text{NaOH}-\text{C}_5\text{H}_{10}\text{NH}$ : isotherm 293 K ( $P = 1$  bar). I:  $\text{NaOH}\cdot\text{H}_2\text{O}$ ; II:  $\text{NaOH}$

**Table 1** Isotherm 323 K determined by ATI, chemical analysis (\*) or the generalized diameter method (\*\*)

w(NaOH)	w(C <sub>5</sub> H <sub>10</sub> NH)	Phenomenon
0.690	0	NaOH·H <sub>2</sub> O
0.599	0	α: Solubility of NaOH·H <sub>2</sub> O in water
0.599	ε	Aqueous invariant liquid L1*
0.300	0.008	Binodal curve
0.101	0.025	Binodal curve
0.082	0.041	Binodal curve
0.058	0.088	Binodal curve
0.05	0.14	Critical point κ**
0.044	0.186	Binodal curve
0.029	0.290	Binodal curve
0.019	0.400	Binodal curve
0.003	0.601	Binodal curve
0.027	0.375	Limit tie-line L1–L2
0.546	0.071	Limit tie-line L1–L2
0.504	0.144	Limit tie-line L1–L2
0.433	0.264	Limit tie-line L1–L2
0.314	0.485	Limit tie-line L1–L2
ε	~1	Organic invariant liquid L2*

**Table 2** Isotherm 313 K determined by ATI, chemical analysis (\*) or the generalized diameter method (\*\*)

w(NaOH)	w(C <sub>5</sub> H <sub>10</sub> NH)	Phenomenon
0.690	0	NaOH·H <sub>2</sub> O
0.568	0	α: Solubility of NaOH·H <sub>2</sub> O in water
0.568	ε	Aqueous invariant liquid L1*
0.123	0.023	Binodal curve
0.086	0.048	Binodal curve
0.063	0.081	Binodal curve
0.05	0.16	Critical point κ**
0.044	0.204	Binodal curve
0.028	0.302	Binodal curve
0.017	0.398	Binodal curve
0.002	0.603	Binodal curve
0.241	0.573	Limit tie-line L1–L2
0.315	0.438	Limit tie-line L1–L2
0.404	0.295	Limit tie-line L1–L2
0.444	0.215	Limit tie-line L1–L2
0.502	0.120	Limit tie-line L1–L2
ε	~1	Organic invariant liquid L2*

The 323 K isotherm is characterized by the crystallization of two solid phases, the anhydrous and the monohydrate sodium hydroxide, and the existence of a large miscibility gap in the crystallization area of the monohydrated compound. The liquid–liquid diphasic equilibrium domain is delimited by the limit tie-line L1–L2 and the

**Table 3** Isotherm 293 K determined by ATI, chemical analysis (\*) or the generalized diameter method (\*\*)

w(NaOH)	w(C <sub>5</sub> H <sub>10</sub> NH)	Phenomenon
0.690	0	NaOH·H <sub>2</sub> O
0.514	0	α: Solubility of NaOH·H <sub>2</sub> O in water
0.514	ε	Aqueous invariant liquid L1*
0.300	0.004	Binodal curve
0.182	0.009	Binodal curve
0.138	0.014	Binodal curve
0.095	0.042	Binodal curve
0.077	0.086	Binodal curve
0.067	0.128	Binodal curve
0.04	0.26	Critical point κ**
0.028	0.352	Binodal curve
0.015	0.460	Binodal curve
0.007	0.568	Binodal curve
0.005	0.600	Binodal curve
0.0001	0.769	Binodal curve
0.0001	0.924	Binodal curve
0.493	0.049	Limit tie-line L1–L2
0.442	0.147	Limit tie-line L1–L2
0.366	0.293	Limit tie-line L1–L2
0.241	0.528	Limit tie-line L1–L2
ε	~1	Organic invariant liquid L2*

critical point κ. The solubility of the anhydrous sodium hydroxide in concentrated aqueous solutions of piperidine is very weak and the liquidus curve is almost merged with the limit binary system H<sub>2</sub>O–C<sub>5</sub>H<sub>10</sub>NH. Consequently, the diphasic domain L + NaOH in the organic side is not easily observable. The two parts of the monohydrated sodium hydroxide liquidus are, respectively, almost overlaid with the invariant points L1 and L2. The diphasic domains L + NaOH·H<sub>2</sub>O in the aqueous and organic sides are thus not easily observable.

This isotherm shows the same equilibrium domains as 323 K and is also characterized by the existence of a miscibility gap in the crystallization area of the monohydrate sodium hydroxide. The miscibility gap is always prevalent and the composition of the invariant liquids L1 and L2 are almost unchanged.

At 293 K the domains are the same as the other isotherms. The demixing zone has slightly decreased and the invariant liquid L1 loses about 15%w of soda.

## Discussion

Three isotherms (293, 313, and 323 K) of the ternary diagram H<sub>2</sub>O–NaOH–C<sub>5</sub>H<sub>10</sub>NH were established by ITA, at atmospheric pressure. All the critical points were

determined by the generalized diameter method and the invariant liquids L1 by acidimetric titration.

Between 293 and 323 K, invariant liquids L2 are globally always very poor in water. So, this study allows us to conclude that the temperature is not a favorable parameter of demixing. This second step of extraction of the hydrazine and piperidine will thus be carried out at room temperature.

After the demixing produced by the liberation of sodium sulfate, we obtained an organic solution titrating 7%w in NAPP and 43%w in piperidine. A calculated quantity of an aqueous solution of sodium hydroxide is then added to this organic mixture recovered after the first demixing. The second demixing leads to a concentration of 9%w in NAPP and 58%w in piperidine. This composition is ideal for the recycling of piperidine and extraction of the NAPP by distillation due to the existence of a positive azeotropic mixture in the binary system  $\text{H}_2\text{O}-\text{C}_5\text{H}_{10}\text{NH}$ .

## Conclusions

Three isothermal sections (293, 313, and 323 K) of the ternary diagram  $\text{H}_2\text{O}-\text{NaOH}-\text{C}_5\text{H}_{10}\text{NH}$  were determined by ITA and chemical titration at atmospheric pressure. The miscibility gap which appears was completely delimited: the critical point of the binodal and the limit tie-line, corresponding to the appearance of monohydrated sodium hydroxide were identified.

Its relevant exploitation is essential for the process optimization of the hydrazine extraction and purification. This extraction process rests on successive operations of demixing before the distillation step. The hydrazine extraction is similar to that of piperidine because this latter, by its excess concentration in the reaction liquors, drives the hydrazine by solvent effect.

This study underlines that the three isotherms have similar demixing features: thus, it does not seem relevant, from an energetic point of view, to implement a separation by demixing beyond the ambient temperature.

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