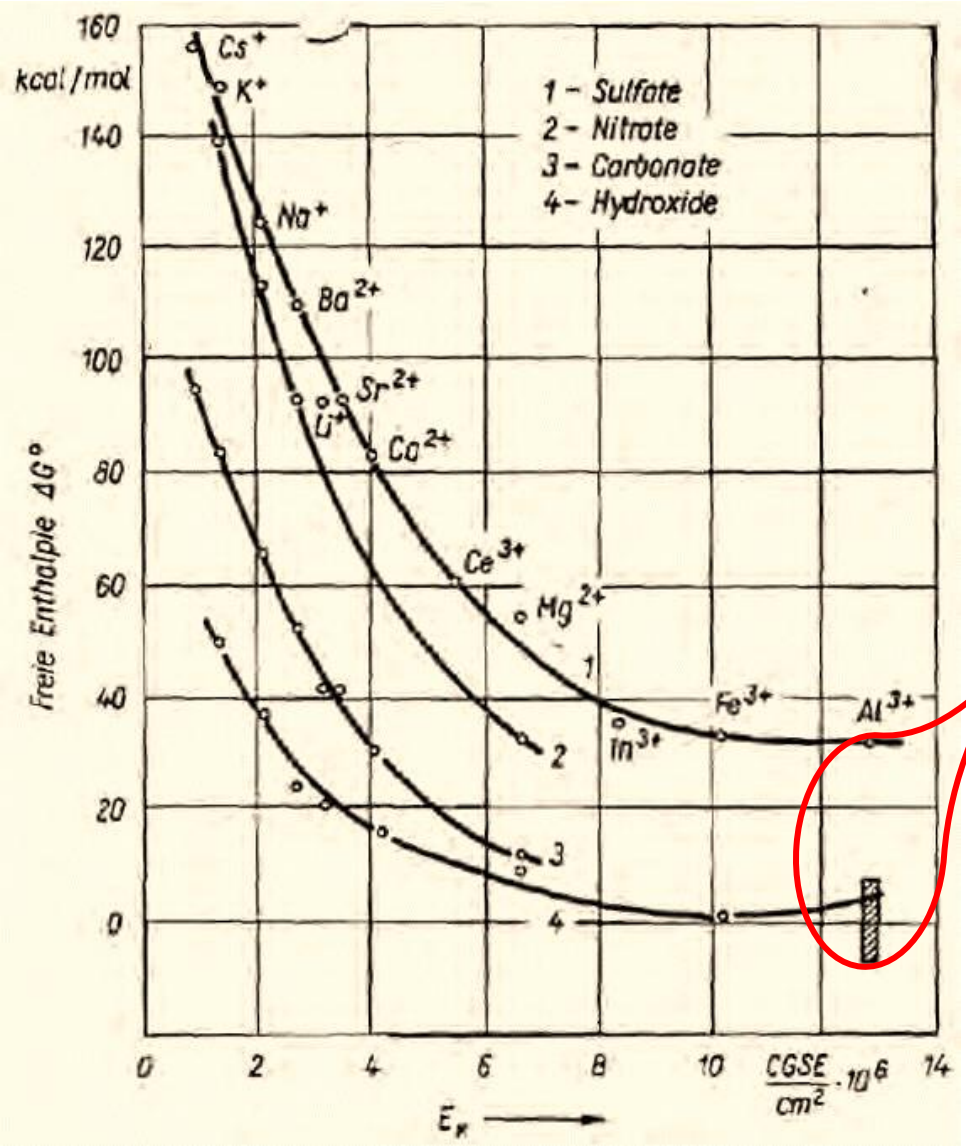
# water soluble aluminum salts

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The low energy level of aluminum compounds and the proximity of their thermodynamic potentials is the fundamental cause of their diversity. This is also the reason for many contradicting results in the numerous conducted studies of aluminum compounds.

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In an acid (alkaline) environment, aluminum is thermodynamically unstable and transforms into a water solution. Because of the significant hydration energy of of $Al^{3+}$ ions in the water solution, they switch into hexaaquaaluminum ions: $Al(H_2O)_6^{3+}$. The polycondensation results in the formation of various poly nuclear aquahydroxyaluminium complex ions:

$$x[Al(H_2O)_6]^{3+} = [Al_x(OH)_y(H_2O)_{2(3x-y)}]^{(3x-y)+} + yH_3O^+$$

The energy level diagram of $Al_2O_3$-HA-$H_2O$ (where HA-mineral acid) type Systems is plotted based on equilibrium data of the dissociation of aquahydroxyaluminium cations and the values of electroconductivity activation energy and viscosity. The driving force of condensation processes of aluminium-oxygen octahedra is expressed by the thermodynamic potentials per mole of water liberated during condensation. The simultaneous existence of various poly-condensation products in aqueous solutions of basic aluminium salts, the discrepancies in literature data available, as well as some peculiarities of the Systems discussed are explained by the small driving force and the presence of product transition activation energy.

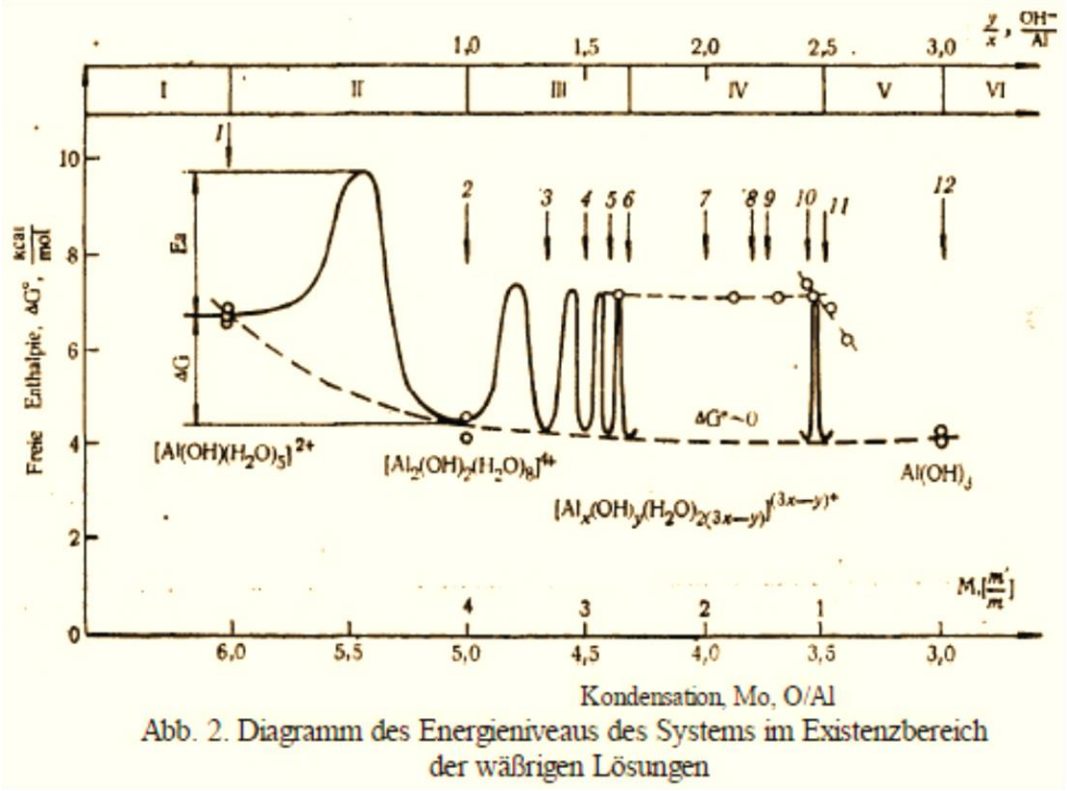


Abb. 2. Diagramm des Energieniveaus des Systems im Existenzbereich der wäßrigen Lösungen

# basicity

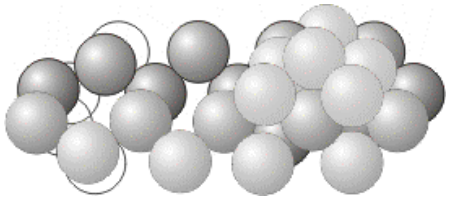

Table 1

| № | | Al | $Al_2O_3$ | $xAl_2O_3yHClzH_2O$ | TC2006-95 (solvo) | | Basicity, % | | БДС EN 883 | | Basicity, a | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | x=1; 0,9<y<2; 4<z<85 | **M** | **$M_2$** | (6-M)/6*100 | a/3*100 | $Al(OH)_aCl_b$ | $Al(OH)_aCl_b(SO_4)_c$ | a>1,05 | |
| | | % | % | $Al_2O_3.MHCl.M_2H_2SO_4.zH_2O$ | $HCl/Al_2O_3$ | $H_2SO_4/Al_2O_3$ | % | % | a+b=3; b=M/2 | a+b+2c=3; c=$M_2$/2 | **(6-M)/2** | **3-M/2-$M_2$** |
| 1 | AH | 34,6 | 65,4 | $Al_2O_3$ $3H_2O$ | 0 | | 100 | | $Al(OH)_3$ | | 3 | |
| 2 | ACH | 5,8 | 11,0 | $Al_2O_31,044HCl40,55H_2O$ | 1,04 | | | 82,60 | $Al(OH)_{2,48}Cl_{0,52}$ | | 2,48 | |
| **3** | **CFS10Al** | **9,9** | **18,8** | **$Al_2O_3.1,4HCl.0,05H_2SO_4.21,4H_2O$** | **1,40** | **0,05** | **75,00** | | **$Al(OH)_{2,25}Cl_{0,7}(SO_4)_{0,025}$** | | | **2,25** |
| 4 | CFS10Al | 10,1 | 19,0 | $Al_2O_3.HCl.0,16H_2SO_4.21,29H_2O$ | 1,00 | 0,16 | 78,00 | | $Al(OH)_{2,34}Cl_{0,50}(SO_4)_{0,08}$ | | | 2,34 |
| 5 | CFS10Al | 10,5 | 19,8 | $Al_2O_3.0,95HCl.0,1H_2SO_4.20,8H_2O$ | 0,80 | 0,09 | 80,83 | | $Al(OH)_{2,43}Cl_{0,48}(SO_4)_{0,05}$ | | | 2,43 |
| 6 | CFS | 5,3 | 10,0 | $Al_2O_3.0,91HCl.0,61H_2SO_4.45,79H_2O$ | 0,91 | 0,61 | 63,33 | | $Al(OH)_{1,90}Cl_{0,46}(SO_4)_{0,30}$ | | | 1,94 |
| 7 | CFS | 3,3 | 6,3 | $Al_2O_3.0,78HCl.1,49H_2SO_4.79,2H_2O$ | 0,78 | 1,49 | 37,33 | | $Al(OH)_{1,12}Cl_{0,39}(SO_4)_{0,74}$ | | | 1,12 |
| 8 | PAC | 13.2 | 24.9 | $Al_2O_3.4HCl.9H_2O$ | 4 | 0 | 33,33 | | $Al(OH)_1Cl_2$ | | 1 | |
| 9 | PAS | 12,2 | 23,1 | $Al_2O_3.2H_2SO_48H_2O$ | | 2 | 33,33 | | $Al(OH)_1$ $(SO_4)_1$ | | | 1 |
| 10 | AC | 11,2 | 21,1 | $Al_2O_36HCl9H_2O$ | 6 | | 0 | | $AlCl_36H_2O$ | | 0 | |
| 11 | AS | 8,6 | 16,2 | $Al_2O_33H_2SO_413H_2O$ | | 3 | | 0 | | $Al_2(SO_4)_316H_2O$ | | 0 |

Note: AH- Aluminium hydroxide,
AC- Aluminium chloride,
AS- Aluminium sulfate

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# equilibria

The intreaction between aluminum, hydrochloric acid and water is complex, complicated, perplexing and as yet debated, but various stages have been recorded and agreed upon. In this paper (Dobrev 1983 ENERGETISCHE CHARAKTERISTIK …) some data are summarized about the hydrolysis of $Al^{3+}$:

Table 2

| Stadium | Mo $[\frac{O}{Al}]$ | Reaktion | $pK$ $-\lg K$ | $\Delta G^\circ$, Kcal/mol | n | $\Delta G^*$, Kcal/mol | Lit. |
|---|---|---|---|---|---|---|---|
| I | 6 | $[Al(H_2O)_6]^{3+} + H_2O \rightleftarrows [Al(OH)(H_2O)_5]^{2+} + H_3O^+$ | 4,95 | 6,747 | 1 | 6,747 | 17 |
| | | $\{Al^{3+} + H_2O \rightleftarrows [Al(OH)]^{2+} + H^+\}$ | 5,03 | 6,856 | | 6,856 | 7 |
| | | $\{Al(H_2O)_6^{3+} \rightleftarrows [Al(H_2O)_5OH]^{2+} + H^+\}$ | 5,10 | 6,953 | | 6,953 | 18 |
| II | 5 | $2Al^{3+} + 2H_2O \rightleftarrows [Al_2(OH)_2]^{4+} + 2H^+$ | 6,27 | 8,550 | 2 | 4,273 | 7 |
| | | $\{[Al(H_2O)_6^{3+} \rightleftarrows [Al_2(OH)_2(H_2O)_8]^{4+} + 2H^+ + 2H_2O\}$ | | | | | |
| | | $[Al(OH)(H_2O)_5]^{2+} + [Al(H_2O)_6]^{3+} \rightleftarrows [Al_2(OH)_2(H_2O)_8]^{4+} + H_3O^+ + H_2O$ | 6,94 | 9,46 | | 4,726 | 18 |
| | | $\{[Al(OH)(H_2O)_5]^{2+} + ]Al(H_2O)_6]^{3+} \rightleftarrows [Al_2(OH)_2(H_2O)_8]^{4+} + H^+ + 2H_2O\}$ | | | | | |
| III | 5 | $[Al_x(OH)_{(2x-2)}(H_2O)_{(2x+4)}]^{(x+2)+}$ | | | | | |
| ↓ | | | | | | | |
| IV | 3 | $[Al_x(OH)_y(H_2O)_{3(3x-y)}]^{(3x-y)+}$ | | | | | |
| V | 3 | $Al^{3+} + 3H_2O \rightleftarrows Al(OH)_3 + 3H^+$ | 9,1 | 12,4 | 3 | 4,134 | 7 |
| | | $\{[Al(H_2O)_6]^{3+} \rightleftarrows Al(OH)_3 + 3H^+ + 3H_2O\}$ | 9,66 | 13,17 | | 4,367 | 20 |
| | | $\{[Al(OH)(H_2O)_5]^{2+} \rightleftarrows Al(OH)_3 + 2H^+ + 2H_2O\}$ | | | | | |
| | | ↑in Lösung | | | | | |
| | | ↓in fester Phase[1] | | | | | |
| VI | 2 | $Al_2O_3.3H_2O \rightleftarrows Al_2O_3.H_2O + 2H_2O$ | | 1,56 | 2 | 5,030 | 21 |
| | | $\{Al(OH)_3 \rightleftarrows AlOOH + H_2O\}$ | | 0,78 | 1 | 5,030 | 21 |
| | 1,5 | $Al_2O_3.3H_2O \rightleftarrows Al_2O_3 + 3H_2O$ | | 4,243 | 3 | 5,665 | 21 |

[1]) Die Werte der freien Enthalpie der Bildung von Verbindungen aus Elementen ($G_i^0$) sind nach [21] bestimmt:

| | $Al_2O_3$ | $Al_2O_3.H_2O$ | $Al_2O_3.3H_2O$ | $H_2O$ |
|---|---|---|---|---|
| $G_i^0$, kcal/mol (298°K) | —104,030 | —484,018 | —628,188 | —71,305 |

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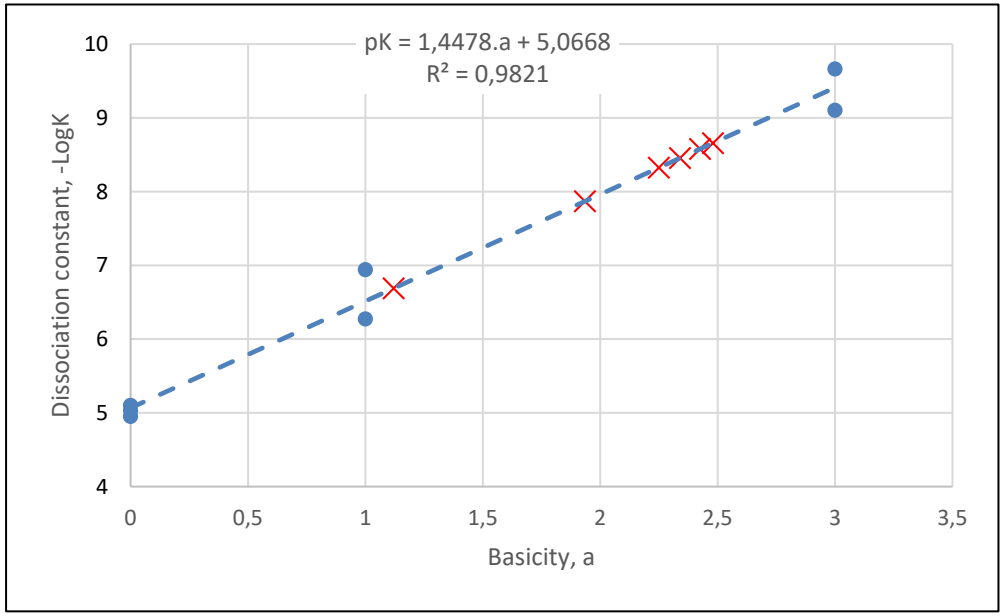
Table 3

| № | | Al % | $Al_2O_3$ % | $xAl_2O_3yHClzH_2O$ x=1; 0,9<y<2; 4<z<85 $Al_2O_3.MHCl.M_2H_2SO_4.zH_2O$ | TC2006-95 (solvo) M $HCl/Al_2O_3$ | $M_2$ $H_2SO_4/Al_2O_3$ | $M_o$ [O/Al]=6-a | Basicity, a a>1,05 (6-M)/2 | 3-M/2-$M_2$ | a | -LogK pKa |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | *3* | | | *3* | *9,66* |
| 1 | AH | 34,6 | 65,4 | $Al_2O_3$ $3H_2O$ | 0 | | *3* | *3* | | *3* | *9,10* |
| 2 | ACH | 5,8 | 11,0 | $Al_2O_3$1,044HCl40,55$H_2O$ | 1,04 | | 3,52 | 2,48 | | 2,48 | 8,66 |
| **3** | **CFS10Al** | **9,9** | **18,8** | **$Al_2O_3$.1,4HCl.0,05$H_2SO_4$.21,4$H_2O$** | **1,40** | **0,05** | **3,75** | | **2,25** | **2,25** | **8,32** |
| 4 | CFS10Al | 10,1 | 19,0 | $Al_2O_3$.HCl.0,16$H_2SO_4$.21,29$H_2O$ | 1,00 | 0,16 | 3,66 | | 2,34 | 2,34 | 8,45 |
| 5 | CFS10Al | 10,5 | 19,8 | $Al_2O_3$.0,95HCl.0,1$H_2SO_4$.20,8$H_2O$ | 0,80 | 0,09 | 3,58 | | 2,43 | 2,43 | 8,58 |
| 6 | CFS | 5,3 | 10,0 | $Al_2O_3$.0,91HCl.0,61$H_2SO_4$.45,79$H_2O$ | 0,91 | 0,61 | 4,07 | | 1,94 | 1,94 | 7,87 |
| 7 | CFS | 3,2 | 6,0 | $Al_2O_3$.0,78HCl.1,49$H_2SO_4$.79,2$H_2O$ | 0,78 | 1,49 | 4,88 | | 1,12 | 1,12 | 6,69 |
| 8 | PAC | 13,2 | 24,9 | $Al_2O_3$4HCl9$H_2O$ | 4 | | *5* | *1* | | *1* | *6,27* |
| 9 | PAS | 12,2 | 23,1 | $Al_2O_3$.2$H_2SO_4$8$H_2O$ | | 2 | *5* | | *1* | *1* | *6,94* |
| 10 | AC | 11,2 | 21,1 | $Al_2O_3$6HCl9$H_2O$ | 6 | | *6* | *0* | | *0* | *5,10* |
| 11 | AS | 8,6 | 16,2 | $Al_2O_3$3$H_2SO_4$13$H_2O$ | | 3 | *6* | | *0* | *0* | *5,03* |
| 12 | | | | | | | *6* | | | *0* | *4,95* |




The depicted dependence reflects the relations between the data in Table 2 (in blue) and products synthesized by us with numbers 2 to 7 in Table 3
As we have shown, the basicity of the solutions under study can easily be calculated from the analytical data of the composition.

Found dependency: **pK = 1,4478.a+5,0668** or **pK = -1,4478.Mo + 13,753**
($R^2$ = 0,9821)

**This is an opportunity to determine the value of the dissociation constant with sufficient confidence.**

**This is particularly useful in the case of high basicity and highly concentrated polyaluminum salt solutions for which standard potentiometric titration methods is not applicable.**

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