Journal of Food Engineering 58 (2003) 373–378

JOURNAL OF FOOD ENGINEERING

www.elsevier.com/locate/jfoodeng

Comparison of electrodialysis and cold treatment on an industrial scale for tartrate stabilization of sherry wines

J. Gómez Benítez [a,*], V.M. Palacios Macías [a], P. Szekely Gorostiaga [b], R. Veas López [c], L. Pérez Rodríguez [a]

[a] *Department of Chemical Engineering, Food Technology and Environmental Technologies, Sciences Faculty, Cadiz University, Puerto Real (Cadiz) 11510, Spain*

[b] *Alimentaria, Avda. Lehendakari Aguirre, 3–6 no. Bilbao 48014, Spain*

[c] *Bodegas Osborne S.A. Fernán Caballero, 3, El Puerto de Santa María (Cádiz) 11500, Spain*

Received 15 February 2002; accepted 14 October 2002

Abstract

Tartrate stabilization on an industrial scale of three sherry wines ("Fino", "Medium" and "Cream") has been carried out by means of cold treatment and electrodialysis with the objective of checking the efficacy of these techniques. This was determined by analysing the compounds involved in the treatments and by conductivity techniques for rapid tartaric stability control (saturation temperature and minicontact test). It has been proven that both cold treatment and electrodialysis imparted tartaric stabilization to all the considered wines, with the latter requiring deionisation rates of 26% in Fino wine and less than 20% in Medium and Cream wines. It has been shown that the minicontact test is a valid method to control the efficacy of the treatments, differentiating between stable and unstable wines.

Keywords: Tartrate stabilization; Potassium bitartrate; Sherry wines; Electrodialysis; Cold treatment; Saturation temperature; Minicontact test

1. Introduction

One frequent cause of loss of stability of a wine is the formation of crystalline salts of potassium bitartrate (KHT) that appears mainly at low temperatures as a consequence of a large decrease in its solubility (Berg & Keefer, 1958; Ratsimba, Laguerie, Biscans, & Gaillard, 1989).

For the stabilisation of wines the addition of metatartaric acid (Celotti, Bornia, & Zoccolan, 1999; Goertges & Stock, 2000; Ribereau-Gayon, Peynaud, Ribereau-Gayon, & Sudraud, 1977) and proton exchange are sometimes used (Mourgues, 1993). Cold treatment can be applied in different ways (Blouin, 1982; Blouin & De Senne, 1983; Maujean, Vallée, & Sausy, 1986), but the most widespread is holding for one week at a temperature near to the freezing point of the wine. This treatment produces a stabilising effect in dry white wines, while this is not so clear in red and natural sweet wines (Guitard, 1983; Serrano, Sudraud, & Ribereau-Gayon, 1983). But such cold treatment has high costs and it is time consuming. Electrodialysis is based on the separation of differently charged ions, by the use of selective permeable membranes, under the action of an electric field (Moutounet, Escudier, & Saint-Pierre, 1994; Ribereau-Gayon, Glories, Maujean, & Dubordieu, 1998). These membranes consist of a polymeric matrix, on which ionised functional groups are covalentely fixed (Gavach, 1992; Guerif, 1993). The first application of electrodialysis to the tartrate stabilization of wines was carried out by Wucherpfennig (1976), who verified its adaptability to each type of wine. Since then, different studies have demonstrated that electrodialysis treatment stabilises appropriately white, rosé and red wines (Moutounet, Saint-Pierre, Batlle, & Escudier, 1997; Uitslag, Minh-Nguyen, & Skurray, 1996). The effect of electrodialysis treatment depends on the deionisation rate (DR) used which varies between 24% and 26% for white and rosé wines, and from 8% to 13% for red wines (Escudier, Moutounet, & Saint Pierre, 1993; Moutounet et al., 1997). It has also been shown that it does not have any appreciable effects on other

* Corresponding author. Tel.: +34-9-5601-6380; fax: +34-9-5601-6411.

E-mail address: juangomez.benitez@uca.es (J. Gómez Benítez).

0260-8774/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0260-8774(02)00421-1

Nomenclature

CT	cold treatment
DR	deionistion rate
ED	electrodialysis
KHT	potassium bitartrate
Mc	minicontact test
Ts	saturation temperature in potassium bitartrate

characteristics of the wine (Biau & Siodlak, 1997; Cottereau, 1993; Riponi, Nauleau, Amati, Arfelli, & Castellari, 1992).

The simplest method to verify the efficacy of a stabilization treatment is to observe the stability of a sample stored at low temperature (Brugirard & Rochard, 1992). But this system is slow, difficult to reproduce and subjective. Tartrate stability can also be determined by means of two tests based on rapid response conductivity techniques. The first one is the saturation temperature (Ts) for KHT of the wine, which globally represents the wine saturation level of this salt, and is measured by the polithermal method (Gaillard, Ratsimba, & Favarel, 1987; García Ruiz, Alcántara, & Martín, 1991). The second method is the minicontact test (Mc) which measures the decrease in the conductivity of a wine kept at low temperature in contact with KHT (Angele, 1992).

Sherry wines are liquor wines elaborated in the south of Spain (C.E., 1988; C.E., 1999), whose manufacture has been broadly described in the bibliography (González Gordon, 1972; Martínez, Pérez Rodríguez, & Benítez, 1997; Pérez Rodríguez, 1991). One of their main problems arises from the use of natural sweet wines, because their high colloids content inhibits KHT crystallisation. during their later tartrate stabilization.

The objective of this work has been to study the application of electrodialysis for tartrate stabilization of Sherry wines to compare its results with cold treatment and to verify its effectiveness for different types of wine.

2. Materials and methods

Trials of application of electrodialysis were carried out on various Sherry wines. For each one of the following types of wine: "Fino" (<2 g/L sugars), "Medium" (40 g/L of sugars) and "Cream" (100 g/L of sugars), different deionisation rates (DR) are applied, the magnitude of which represents the decrease in % of wine conductivity during the treatment. Also, a cold treatment is applied to these wines, which allows one to compare the results of these two techniques. The work is carried out in a commercial cellar of the Denominations of Origin Jerez-Xérèz-Sherry y Manzanilla de Sanlucar de Barrameda (Spain).

2.1. Description of the industrial plants

For the electrodialysis trials an equipment with a total surface of 25 m^2 and a treatment capacity of 25 hL/h was used. It had a discontinuous operation regime, circulating the wine between the membrane reactor and a tank, until the wine reaches the desired conductivity, upon which a new cycle begins.

For the cold treatment trials a standard system where the wine is refrigerated to a temperature near its freezing point and kept at this temperature for one week was used. The installation had a refrigeration capacity of 85,000 frigories (one frigorie is equivalent to 1000 calories extracted per hour) and the insulated storage tanks had a volume of 23,000 L.

2.2. Determination of saturation temperature and minicontact test

The determination of Ts and the Mc test uses fully automated equipment. For the Ts determination ramps of temperature between 5 and 30 °C and a KHT dose of 4 g/L were used. In each ramp the conductivity and the temperature were measured, the Ts being determined from the crossing point of the two graphs. For the minicontact test a temperature of 0 $°C \pm 0.1$, a KHT dose of 4 g/L, and a duration between 10 and 18 min, depending on the stability of the sample, were used.

2.3. Analytical determinations

For the determination of the alcohol content, pH, total acidity, volatile acidity free and total SO_2, and sulphates, the European Official Methods of Analysis (Ministerio de Agricultura, Pesca y Alimentación, 1993) were used. Absorbances at 420 and 520 nm were measured by a UV–VIS spectrophotometer with a cell of 10 mm pathlength. Sodium and potassium were determined by flame emission photometry, and calcium and magnesium by atomic absorption spectrophotometry. Tartaric, malic, lactic and acetic acids were analysed by HPLC (Frayne, 1986), with a UV detector at 214 nm. All the determinations were carried out twice, and the arithmetic means of the results are presented.

2.4. Sensorial analysis

Sensory analyses were carried out by five expert tasters of the cellar where the trials were done, using the bilateral test technique in coupled samples (Peynaud, 1987). All the samples treated by electrodiálisis were compared with the corresponding cold treated sample. Each taster indicated their preference in each couple of samples, and carried out general observations on the effects of the considered treatments on the sensory characteristics of the wines.

3. Results

3.1. Effects of the treatments on most common enological parameters

The influence of electrodialysis treatment on the alcohol content, colour intensity ($A_{420}+A_{520}$), pH, volatile acidity and free and total SO_2 was small or negligible, while the effect on the titratable acidity was small and in direct relationship with the DR (Table 1a–b), as shown by Moutounet et al. (1997). The cold treatment produced a pH decrease of 0.2 units in the Fino wines, while the maximum decrease produced by electrodialysis in these wines was only 0.05 units. This small electrodialysis effect on the pH was due to the opposing actions created by cationic and anionic membranes, because the effect on the pH of the elimination of protons in the cationic membrane was compensated by that of the anions eliminated in the anionic membranes. The cold treatment also reduced the colour intensity to a greater degree, especially in the Medium and Cream wines because of a partial insolubilisation of its colouring matter at low temperature.

3.2. Effects of the treatments on the main cation concentrations

With regard to potassium, the electrodialysis produced an appreciable reduction in its concentration for

Table 1
Variations in most common enological parameters and tartrate stability during electrodialysis and cold treatments

Treatments	Fino							
Deionisation rate (%)	Control[a]	ED[b]						CT[c]
		19.6	26.7	30.4	32.3	34.2	40.4	
(a) Fino wine								
Alcohol content (% vol.)	15.1	15.0	15.0	14.9	14.9	15.0	15.0	15.1
A_{420}	0.014	0.013	0.015	0.024	0.019	0.020	0.015	0.015
A_{520}	0.006	0.004	0.004	0.012	0.008	0.009	0.005	0.004
PH	3.18	3.16	3.17	3.13	3.16	3.16	3.14	2.98
Titratable acidity (g/L)	4.23	4.01	3.90	3.90	3.92	3.90	3.83	3.84
Volatile acidity (g/L)	0.16	0.14	0.14	0.13	0.08	0.10	0.15	0.13
Free/total SO_2 (mg/L)	3/27	1/25	1/27	2/20	1/19	3/20	1/18	3/24
Ts (°C)[d]	23.9	19.7	18.4	16.6	16.3	16.0	13.7	13.0
Mc (μS/cm)[e]	85	61	9	6	1	6	3	1
Tartrate stability[f]	+++	++	–	–	–	–	–	–

	Medium					Cream		
	Control[a]	ED[b]			CT[c]	Control[a]	ED[b]	CT[c]
		20.8	25.2	30.1			18.3	
(b) Medium and Cream wines								
Alcohol content (% vol.)	15.3	15.2	15.2	15.2	15.3	15.52	15.31	15.5
A_{420}	0.055	0.057	0.057	0.058	0.044	0.074	0.069	0.054
A_{520}	0.022	0.023	0.023	0.021	0.020	0.030	0.026	0.017
pH	3.54	3.50	3.52	3.51	3.45	3.43	3.37	3.43
Titratable acidity (g/L)	4.12	4.11	4.07	4.03	4.02	4.09	3.94	3.88
Volatile acidity (g/L)	0.60	0.62	0.72	0.69	0.68	0.65	0.63	0.67
Free/total SO_2 (mg/L)	3/13	3/11	3/11	1/12	3/12	1/14	1/13	3/12
Ts (°C)[d]	24.4	18.8	18.4	16.6	19.5	21.0	16.6	19.1
Mc (μS/cm)[e]	67	9	5	5	9	9	5	8
Tartrate stability[f]	++	–	–	–	–	–	–	–

[a] Control, wine before treatment.
[b] ED, electrodialysis.
[c] CT, cold treatment.
[d] Ts, saturation temperature.
[e] Mc, minicontact test.
[f] Tartrate stability: (+++) big sized sediment; (++) medium sized sediment; (–) without sediment.

all tested wines, its amount being directly related to the applied DR (Table 2a–b). Conversely, the effect of the cold treatment on this cation varied in each of the different types of wines, being considerable in the Fino and Medium wines and of significantly reduced magnitude in the Cream wine, owing to the high degree of inhibition of precipitation of KHT in this type of wine. The electrodialysis also produced an appreciable decrease in the concentrations of the Ca^{+2} and Mg^{+2} ions, while during the cold treatment an increase in their concentrations was frequently produced due to the diatomaceous earths used in the filtration after cold treatment. In any case, it should be pointed out that no problems of stability are usually observed in Sherry wines due to calcium. It should also be highlighted that the effect of the electrodialysis on the sodium concentration was very reduced, as shown by Riponi et al. (1992).

3.3. Effects of the treatments on the main anion concentrations

It was observed that electrodialysis produced an appreciable reduction in the sulphate content, its quantity being in direct relationship with the DR used (Table 2a–b). That is especially interesting in wines with a high sulphate content, such as those where the practice of plaster use in winemaking is carried out, which was the case with the wines used in this work. Plaster use (addition of $CaSO_4$) is a treatment authorised in Sherry wines to reduce the pH of the musts before fermentation (Gómez Benítez, Grandal Delgado, & Diez Martín, 1993). The effect of the electrodialysis treatment on the tartrate ion was much smaller, 5 meq/L being the maximum decrease in Fino wine against a decrease of 38 meq/L in the sulphate ions in the same wine. This indicates that electrodialysis preferentially separates the sulphate (Wucherpfennig, 1976), which can be explained because the sulphate is an anion of a much stronger acid and therefore more active in the membranes than the tartrate. In wines with a low sulphate concentration, the effect on the tartrate concentration would be undoubtedly larger. Cold treatment produced a larger decrease in the tartrate content than electrodialysis (13 meq/L in the Fino wine). Lastly, neither the electrodialysis nor the cold treatment produced appreciable effects on the contents of malate, lactate and acetate at the concentrations of these ions in Sherry wines.

Table 2
Variations in main cation and anion concentrations during electrodialysis and cold treatments

Treatments / Deionisation rate (%)	Fino							
	Control[a]	ED[b]						CT[c]
		19.6	26.7	30.4	32.3	34.2	40.4	
(a) Fino wine								
Na (mg/L)	31	30	30	32	30	27	25	30
K (mg/L)	695	535	498	450	425	425	330	520
Ca (mg/L)	102	72	72	71	70	70	67	90
Mg (mg/L)	86	66	60	60	60	60	48	78
Sulphate (g/L K_2SO_4)	2.72	1.63	1.36	1.10	1.14	1.08	0.87	2.72
Tartaric acid (g/L)	2.43	2.33	2.16	2.10	2.10	2.08	2.05	1.43
Malic acid (g/L)	0.177	0.189	0.146	0.153	0.153	0.153	0.146	0.161
Lactic acid (g/L)	0.214	0.238	0.249	0.246	0.230	0.247	0.255	0.263
Acetic acid (g/L)	0.140	0.136	0.130	0.125	0.109	0.115	0.140	0.125

	Medium					Cream		
	Control[a]	ED[b]			CT[c]	Control[a]	ED[b] 18.3	CT[c]
		20.8	25.2	30.1				
(b) Medium and Cream wines								
Na (mg/L)	52	46	41	38	54	31	30	33,8
K (mg/L)	1470	825	755	620	820	705	520	695
Ca (mg/L)	97	97	97	92	120	95	70	120
Mg (mg/L)	84	84	84	78	84	66	46	78
Sulphate (g/L K_2SO_4)	2.52	1.47	1.33	1.21	2.52	2.16	1.27	2.16
Tartaric acid (g/L)	1.55	1.41	1.38	1.33	1.13	1.59	1.41	1.35
Malic acid (g/L)	0.200	0.206	0.192	0.192	0.215	0.132	0.148	0.158
Lactic acid (g/L)	1.397	1.355	1.351	1.341	1.418	n.d.	n.d.	1.406
Acetic acid (g/L)	0.590	0.600	0.650	0.675	0.653	0.590	0.575	0.580

[a] Control, wine before treatment.
[b] ED, electrodialysis.
[c] CT, cold treatment.

Table 3
Sensorial analysis of the wines treated by electrodialisis and cold treatment (number of times that the sample has been preferred)

Treatment	ED[a]	CT[b]	ED[a]	CT[b]	ED[a]	CT[b]	ED[a]	CT[b]	ED[a]	CT[b]	ED[a]	CT[b]
(a) Fino wine												
Deionisation rate (%)	19.6	–	26.7	–	30.4	–	32.3	–	34.2	–	40.4	–
Preferences	1	4	1	4	0	5	0	5	0	5	0	5
	Medium						Cream					
	ED[a]	CT[b]	ED[a]	CT[b]	ED[a]	CT[b]	ED[a]	CT[b]				
(b) Medium and Cream wines												
Deionisation rate (%)	20.8	–	25.2	–	30.1	–	18.3	–				
Preferences	1	4	1	4	0	5	2	3				

[a] ED, electrodialysis.
[b] CT, cold treatment.

3.4. Effects of the treatments on tartrate stability

The cold treatment ensured tartrate stability in the three studied wines (Table 1a–b). To get a similar stability with electrodialysis it was necessary to apply a DR value higher than 26% in the Fino wine, while Medium and Cream wines needed DR values lower than 20%. The electrodialysis produced a reduction in Ts directly related to the DR used, while the Mc values decreased to values smaller than 10 μS/cm, and then stayed more or less constant. The cold treatment produced considerable decreases in Ts and Mc mainly in the Fino wines, because of its large effect on the bitartrate ion. The stability criteria for white table wines recommended by the manufacturers of the equipment were used (stable wines when $Ts < 12.5$ °C or $Mc < 20$ μS/cm) (Gaillard, Ratsimba, & Favarel, 1990). Then, the Mc gave correct information on stability, with all the stable wines having a value of Mc less than 20 μS/cm. Meanwhile Ts gave a misleading information because following Ts criteria all the treated wines would be unstable.

4. Effect on the sensorial characteristics of the wines

Most of the tasters preferred the cold treated samples (Table 3), indicating that the electrodialysis produced a slight reduction in the aroma and flavour of the wine in relation to the applied DR. In their general opinion the observed reductions of the aroma and flavour were acceptable, whenever the value of the DR of 30% was not exceeded. The aromatic loss taking place can have been produced, at least partly, because the installation was not entirely rendered inert.

5. Conclusions

The treatment of Sherry wines by electrodialysis and cold treatment on an industrial scale produces their tartrate stabilization in an effective way. To obtain an appropriate tartrate stability a deionisation rate of 20% is applied for the Medium and Cream wines and a rate of 26% for the Fino wines. Electrodialysis reduces the concentration of sulphates more than the tartrates. It is observed that the electrodialysis treatment affects slightly the sensory characteristics of the Sherry wines, depending on the applied deionisation rate, but was acceptable whenever deionisation rates lower than 30% were used.

References

Angele, L. (1992). STABISAT: contrôle de la stabilité tartrique et gestion de la production. *Revue des Oenologues, 65*, 43–47.

Berg, H. W., & Keefer, R. (1958). Analytical determination of tartrate stability in wine. (I) Potassium bitartrate. *American Journal of Enology and Viticulture, 9*, 180–193.

Biau, G., & Siodlak, A. (1997). Conception, réalisation et utilisation d'une unité industriale de stabilisation tartrique. *Revue Française d'Oenologie, 162*, 18–20.

Blouin, J. (1982). Les techniques de stabilisation tartrique des vins par le froid. *Journal International des Sciences de la Vigne et du Vin, 16*(1), 63–77.

Blouin, J., & De Senne, A. (1983). Essai d'un appareil de traitement des vins par le froid en continu. *Connaissance de la Vigne et du Vin, 17*(2), 135–150.

Brugirard, A., & Rochard, J. (1992). Prévention des précipitations tartriques. In *Aspects pratiques des traitements thermiques des vins* (pp. 74–105). Chaintré, France: Bourgogne-publications.

C. E. (1988). Reglamento (C.E.E.) 4252/88 de 21 de diciembre de 1988 relativo a la elaboración y a la comercialización de los vinos de licor producidos en la Comunidad. D.O.C.E. L373, 59–65.

C. E. (1999). Reglamento (C.E.) 1493/1999 del Consejo de 17 de Mayo de 1999 por el que se establece la organización común del mercado vitivinícola. D.O.C.E. L179, pp. 1–84.

Celotti, E., Bornia, L., & Zoccolan, E. (1999). Evaluation of the electrical properties of some products used in the tartaric stailization of wines. *American Journal of Enology and Viticulture, 50*(3), 343–350.

Cottereau, P. (1993). Stabilisation tartrique des vins du Beaujolais par électrodialyse. *Revue des Oenologues, 69S*, 43–46.

Escudier, J. L., Moutounet, M., & Saint Pierre, B. (1993). Stabilisation tartrique des vins par électrodialyse. *Revue des Oenologues, 69S*, 35–37.

Frayne, R. F. (1986). Direct analysis of major organic components in grape must and wine using high performance liquid chromatography. *American Journal of Enology and Viticulture, 37*(4), 281.

Gaillard, M., Ratsimba, B., & Favarel, J. L. 1987. Procédé et installation pour déterminer la température de saturation d'un sel naturel dans le vin. *Demande de brevet d'invention*, no publication 2611910, no. enregisrement 87 02738 (France).

Gaillard, M., Ratsimba, B., & Favarel, J. L. (1990). Stabilité tartrique des vins: comparaison de différens tests, mesure de l'influence des polyphenols. *Revue Française d'Oenologie, 123*, 7–13.

García Ruiz, J. M., Alcántara, R., & Martín, J. (1991). Evaluation of wine stability to potassium hydrogen tartrate precipitation. *American Journal of Enology and Viticulture, 42*(4), 336–340.

Gavach, C. (1992). L' électrodialyse: principes. *Revue Française d'Oenologie, 137*, 53–58.

Goertges, S., & Stock, R. (2000). Crystals in wine. Crystal stabilization and stability control. *Deutsche-weinmagazin, 2*, 24–28.

Gómez Benítez, J., Grandal Delgado, M. M., & Diez Martín, J. (1993). Estudy of the acidification of sherry musts with gypsum and tartaric acid. *American Journal of Enology and Viticulture, 44*, 400–404.

González Gordon, M. (1972). *Sherry. The noble wine*. London: Wine & Spirit Publications.

Guerif, G. (1993). L' électrodialyse appliquée à la stabilisation tartrique des vins. *Revue des Oenologues, 69S*, 39–42.

Guitard, A. (1983). La stabilisation physique des vins. La préparatión des vins avant leur mise en bouteilles. In *Proceedings of the Journée de rencontres oenologiques de l'association des oenologues de la Faculté de Pharmacie de Montpellier*. Montpellier, Francia, pp. 17–31.

Martínez, P., Pérez Rodríguez, L., & Benítez, T. (1997). Velum formation by flor yeast isolated from Sherry Wine. *American Journal of Enology and Viticulture, 48*(1), 55–61.

Maujean, A., Vallée, C., & Sausy, L. (1986). Influence de la granulométrie des cristaux de tatre de contact et des traitements de collage sur la cinétique de cristallisation du bitartrate de potassium dans les vins. *Revue Française d'Oenologie. Cahier Scientifique, 104*, 34–41.

Ministerio de Agricultura, Pesca y Alimentación. (1993). *Métodos oficiales de análisis. Tomo II. Mostos y vinos*. Ed. Dirección General de Política Alimentaria. Madrid, España.

Mourgues, J. (1993). Utilisitation des résines échangeuses d'ions. *Revue des Oenologues, 69S*, 51–54.

Moutounet, M., Escudier, J. L., & Saint-Pierre, B. (1994). L'électrodialyse, adaptation à la stabilisation tartrique des vins. In: *Les acquisitions récentes dans les traitements physiques du vin. Incidences sus la composition chimique et les qualités organoleptiques des vins* (pp. 103–115). Paris, France: Lavoisier Tec&Doc.

Moutounet, M., Saint-Pierre, B., Batlle, J. L., & Escudier, J. L. (1997). Le stabilisateur tartrique: principe et description du procédé. *Revue Française d'Oenologie, 162*, 15–17.

Pérez Rodríguez, L. (1991). La crianza del vino de Jerez. *Vitivinicultura, 9*, 19–22.

Peynaud, E. (1987). *El gusto del vino. El gran libro de la degustación*. Madrid, Spain: Miundi-Prensa.

Ratsimba, B., Laguerie, C., Biscans, B., & Gaillard, M. (1989). Solubilité du bitartrate de potassium dans les solutions hydroalcooliques: influence de paramètres spécifiques à l'oenologie. *Bulletin de la Societe Chimque de France, 3*, 325–330.

Ribereau-Gayon, J., Peynaud, E., Ribereau-Gayon, P., & Sudraud, P. (1977). *Sciences et techniques du vin. T4. Clarification et stabilisation. Matériel et installations*. Paris: Dunod.

Ribereau-Gayon, P., Glories, Y., Maujean, A., & Dubordieu, D. (1998). *Traité d'oenologie.T2. Chimie du vin. Stabilisation et traitments*. Paris: Dunod.

Riponi, C., Nauleau, F., Amati, A., Arfelli, G., & Castellari, M. (1992). Essais de stabilisation tartrique des vins au moyen de l'électrodialyse. *Revue Française d'Oenologie, 137*, 59–63.

Serrano, M., Sudraud, P., & Ribereau-Gayon, P. (1983). Prevention des precipitations tartriques dans les vins au moyen du traitement en continu par le froid. *Journal International des Sciences de la Vigne et du Vin, 2*, 121–136.

Uitslag, H., Minh-Nguyen, S. G., & Skurray, G. (1996). Removal of tartrate from wine by electrodialyisis. *Australian and New Zealand Grapegrower and Winemaker, 390a*, 75–78.

Wucherpfennig, K. (1976). Impediment to the tartar separation with electrodialysis. *Industria delle Bevande, 5*, 97–113.