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The history of vinegar and of its acetification systems

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Abstract

The history of vinegar and of its acetification systems. – *A rapid historical survey from the XVIth to the XXth centuries serves to order and situate the principal landmarks which have contributed to the present level of scientific knowledge, and of the technological advances in vinegar production.*

The first proposition of an elaboration of a chemical equation, the description of the mother of vinegar, the identification of the importance of wood shavings and of air led to the development of a rapid and more stable method. As soon as scientific knowledge established rules, the resultant profit contributed to the rapid development of corresponding technologies.

*This progress prepared the way for the valuable contribution of Pasteur: the description of "*Mycoderma aceti*", the role of oxygen in the atmosphere for the oxidation of ethanol to acetic acid, the possibility of continuous production, and eventually the acetification of high strength vinegar. The submerged fermentation system and computerization have both contributed to these last aspects of technological advance.*

From the end of the 19th century and throughout the 20th century, the development of industrial equipment and process significantly increased the production and the quality of vinegar. Probably the most significant step forward was the development of the submerged system in 1949. This communication attempts a rapid historical review, with corresponding references, of the fundamental advancements which have contributed to the present understanding and knowledge of the elaboration of vinegar.

Keywords: *Wood shavings, generator, submerged acetification system, rotation acetifier.*

Résumé

L'histoire du vinaigre et de ses systèmes d'acétification. – *Cet article est un résumé historique rapide du XVI^{e} au XX^{e} siècle, avec les références correspondantes, des progrès fondamentaux qui ont contribué à la connaissance et à la compréhension de l'élaboration du vinaigre.*

*La description de la mère de vinaigre, l'équation chimique de la fermentation acétique et l'importance des copeaux de bois et de l'air ont conduit à un mode de fabrication du vinaigre plus rapide. Ces progrès ont ouvert la voie à l'importante contribution de Pasteur: la présence de «*Mycoderma aceti*», le rôle de l'oxygène atmosphérique pour l'oxydation de l'alcool en acide acétique, la possibilité du système d'acétification en continu, et celui à haut degré. Le système immergé et l'informatique ont contribué tous deux à ces derniers aspects du progrès technologique.*

L'évènement le plus significatif pour le développement de l'équipement industriel et du procédé d'acétification a certainement été le système immergé en 1949.

Depuis la fin du XIX^{e} siècle et durant tout le XX^{e}, le développement des équipements industriels et des procédés ont augmenté la production et la qualité du vinaigre. L'avancement probablement le plus significatif a été le développement du système immergé.

Mots-clés: *Copeaux de bois, systèmes d'acétification tournant et immergé.*

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Introduction

A good grasp of background history is always beneficial for the deeper understanding of a subject, and serves as a basis for significant contribution to its advance. Vinegar is no exception to this. This publication attempts a rapid historical review, with corresponding references, of the fundamental advancements which have contributed to the present understanding and knowledge of the elaboration of vinegar. At the end of the XVIth century knowledge about vinegar making had not progressed further than a range of different techniques, all empirical, with uncertain production results, and no scientific knowledge to speak of.

Surprising uses revealed by vinegar history

The word **vinegar** comes etymologically from the French word "vinaigre" which means "sour wine". The origin of vinegar is certainly connected to the discovery of wine. If wine is left open to air, it rapidly becomes acid and it turns into "sour wine". Recognizable both by its smell and its pungent taste, this liquid has a long tradition. The history of vinegar helps us realize that it is one of the beautiful and great gifts given to mankind by nature.

The first recorded mention of vinegar was in around 3000 B.C., when the Babylonians used the fruit and sap of the date palm as raw material to produce alcoholic beverages. They were transformed naturally into vinegar in contact with air. The Babylonians used it as a food and as a preserving or pickling agent. Residues of vinegar were found in Egypt in urns dating back to 3000 B.C. Texts about vinegar dating from 1200 B.C. have also been found in China. In ancient Greece, in about 400 B.C., Hippocrates, the father of modern medicine, recommended cider vinegar mixed with honey to treat coughs and colds. All through the ages, diluted vinegar has been used as a vitalizing and energizing tonic. Roman soldiers called this refreshing beverage "posca". Vinegar was also used to clean and disinfect wounds. One of the spin-offs of the study of history through the ages is that it brings to light, quite incidentally, some surprising uses of vinegar. For instance, the Carthaginian general Hannibal used vinegar to cross the Alps to invade Italy in 218 B.C. Titus Livius better known as Livy, wrote in his book «the History of Rome» Chapter XXI (in the Punic Wars): «Hannibal's soldiers were told to cut through the rock that barred their way over the Alps. They built up against it an enormous pile of tall trees which they had felled and lopped, and when the wind was strong enough to blow the fire into a blaze they set light to the pile. When the rock was red hot they threw vinegar on it (the sour wine the soldiers drank) to make it friable, and opened a way through it with their tools, making a way down the steep slope with winding tracks and adapting the gradient, so that not only the pack animals but even the elephants could be led down». Pliny wrote in his book «Natural History», chapter IX, that Cleopatra, the queen of Egypt, made a bet with the Roman general Mark Anthony that she could host the most expensive banquet costing ten million sesterces. He laughed at her, but during the meal, for the desert, she had a bowl of strong vinegar brought in and dissolved a pearl of inestimable value in it, and then drank the resulting potion. Vinegar is mentioned and used as a drink and medicine in the Old and the New Testament of the Bible (Mazza and Murooka 2009).

It is said that Louis XIII (1601-1643), King of France, paid up to 1.3 million francs for every battle fought, to buy vinegar for use in cleaning the canons of his army. Vinegar was well known by the European alchemists of the Middle Ages. After pouring vinegar on lead, they produced "lead sugar", used to sweeten cider until the 19th century. Unfortunately, lead acetate being a poison resulted in the death of several cider drinkers. The cabalistic symbol (Fig. 1A) of a cross in the middle of four circles (Bourgeois 1999) was used by alchemists as the symbol of vinegar.

Basilius Valentinus (1565-1624) wrote at the beginning of the 15th century that it was hardly possible to do anything useful in alchemy without the help of vinegar.

Between 1347 and 1771 several European towns were hit by the plague at various times. It is estimated that there were 50 million victims of this disease, which was vectored to man by flea ridden rats. In 1721, the plague hit the towns of France so violently that it became impossible to bury the dead suitably. To remedy the situation, prisoners were forced to bury the very contagious corpses of the victims. According to the legend, whereas most prisoners died, there were four prisoners who managed to survive by drinking daily large quantities of vinegar macerated with garlic. Today it is still possible to buy this vinegar called "the four thieves vinegar", named thus, because they proverbially robbed the corpses they were burying.

The aristocrats of the 17th and 18th centuries held sponges dipped in vinegar to their noses, to neutralize the foul smell of sewage and waste prevalent at that time. Little silver tins, called "vinaigrettes" were used to carry these soaked sponges, which were kept in the knobs of their walking sticks. Vinegar was also used for bodily hygiene. At the court of Versailles the ladies used it both for their ablutions and medicinal use (Mazza and Murooka 2009).

The fabrication of vinegar was left to the care of nature for a long time and it was not until the Middle Ages that

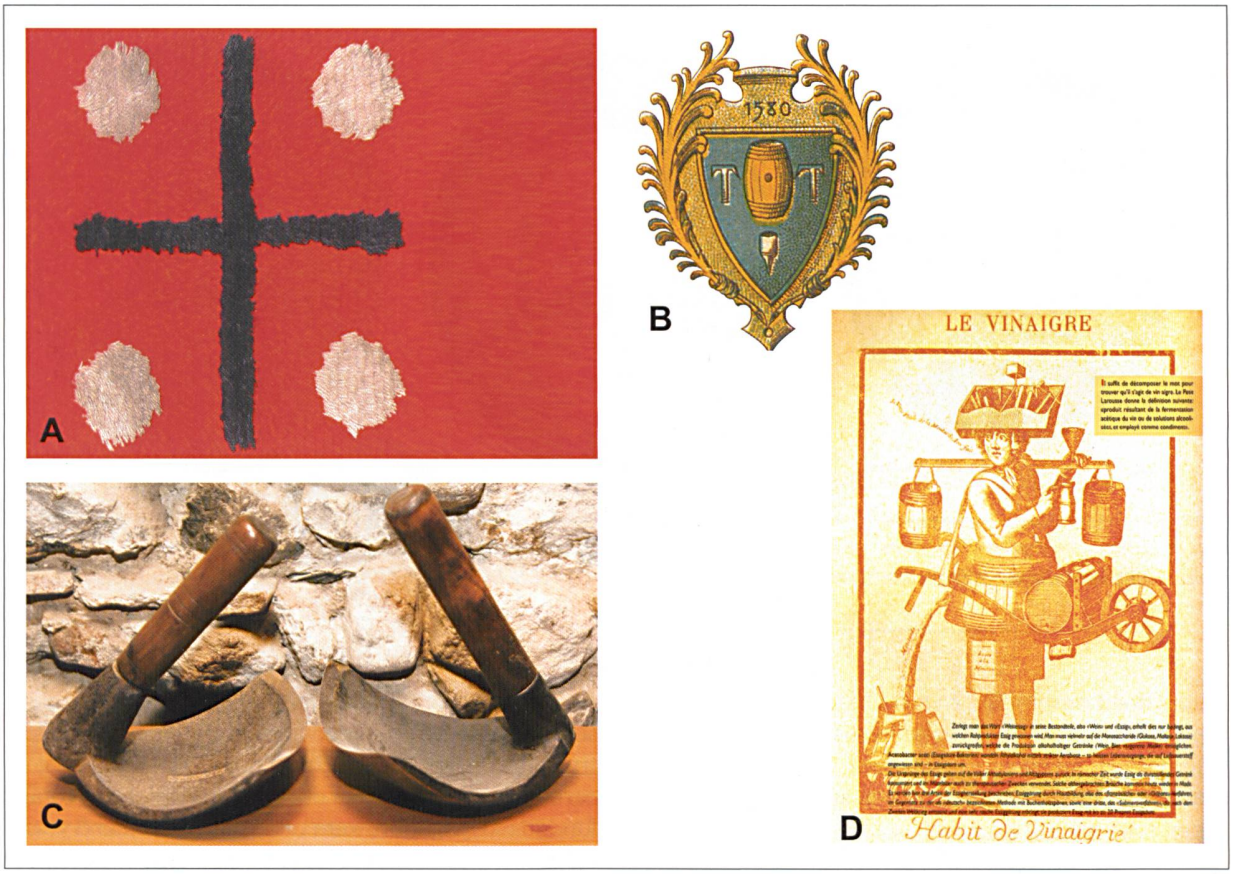


Fig. 1. Old time pictures.
A) Vinegar symbol for the alchemists (source: Bourgeois J.F. private collection). B) Coat of arms of vinegar brewers (1580) (source: Lefebvre C. 2000, with kind permission). C) Coopers "adzes" (source: private collection J.F. Bourgeois). D) Vinegar street vendor with wheel barrow, barrel, funnel and pots (source: Bourgeois J.F. 1999).

it was produced industrially. In 1394 the vinegar corporation was upgraded into a guild-mastership, and part of the initiation ceremony was making a solemn oath never to reveal the secrets of vinegar fabrication. That same year, in order to respond to the demand for a profitable market for vinegar, a group of wine merchants developed a continuous fabrication system, the Orléans method. Oak barrels were used for the fermentation, and the vinegar was siphoned off through a tap at the bottom of the barrel. The mother of vinegar was left in the barrels in about 15% of the residual vinegar. Then a fresh addition of wine or cider was added to the barrels, and the fabrication of vinegar rapidly started up again.

During the Renaissance, the vinegar industry in France was very prosperous. Various flavoured vinegars were produced with different spices, herbs, fruits and even flowers. At the beginning of the 18th century, there were more than a hundred varieties of macerated vinegars.

King Henry III (1551-1589) founded in 1580 in Orléans the corporation of mustard and vinegar brewers. Their coat of arms represents a barrel, a funnel and two adzes (Fig. 1B). These are still in use in the present (Fig. 1C). Each one weighs 3 kg, a heavy weight for the cooper to use! The cutting edge is as sharp as a knife.

The Figure 1D is allegorical, but it puts together the utensils necessary for the vinegar-brewer-cum-street-vendor, such as barrel, funnel, pots, and wheelbarrow. As seen in the coat of arms (Fig. 1B), the funnel served to pour the mustard into the first container brought by the housewife. The vinegar then rinsed out the mustard stuck in the funnel, and this vinegar was poured into a second container. No waste! It was cloudy with the mustard, and sold by this barrow boy, or street vendor. (Note the "accent aigu" on the word "vinaigrié", because it is written in old French).

The first scientists to study vinegar

Hermann Boerhaave (1668-1738)

He invented a continuous process (the precursor for automation of acetification) which was very modern in those days, as was the understanding for the necessity

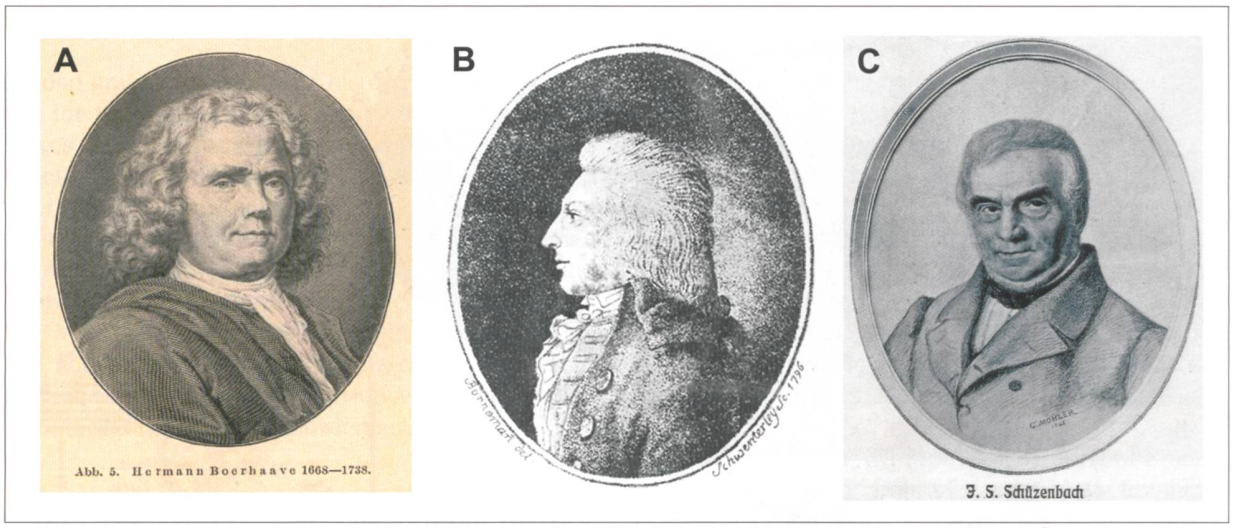


Fig. 2: Famous vinegar researchers. A) H. Boerhaave (1668-1738) (source: Wüstenfeld H. 1930). B) C.H. Persoon (1761-1836) (source: http://es.wikipedia.org/wiki/Christiaan_Hendrik_Persoon). C) J.S. Schüzenbach (1793-1869) (source: Wüstenfeld H. 1930).

of air. Boerhaave (Fig. 2A), a Dutch doctor, showed the importance of the "vegetal substance" or "flower" (mother of vinegar). Boerhaave introduced wood shavings to increase the oxidation surface.

Christian Hendrik Persoon (1761-1836)

Persoon (Fig. 2B) a botanist was born in South Africa at the Cape of Good Hope. As a mycologist he added to Linnaeus' mushroom taxonomy. Inspired by the ideas of Fabroni and Chaptal (see Pasteur 1868), he attributed the vinegar production to the film on the surface of wine left open to the air. Assuming it to be a fungus, he gave it in 1822 the name of *Mycoderma*.

Johann Wolfgang Döbereiner (1780-1849)

Döbereiner, a German chemist (Fig. 3A), was taught by his mother how to produce 16 different types of vinegar (Döbereiner 1819). Culinary art and chemistry led him to write in 1822 the now well known equation: $C_2H_5OH + O_2 = CH_3COOH + H_2O$ (alcohol + oxygen are transformed in acetic acid and water). According to Pasteur (1868), Döbereiner published in 1823 this chemical equation, in Annales de chimie et de physique (Pasteur Vallery-Radot 1924) and in Journal de Schweigger.

The Figure 3B shows the first page of another publication by Döbereiner in 1819: "Anleitung zur kunstmässigen Bereitung verschiedener Arten Essige" ("Introduction in the art of the production of various sorts of vinegars"). Döbereiner wrote in 1814, in the foreword of the first edition of this book: "As a chemist, and as I know exactly the different manufacturing processes of vinegar brewers, and as I have practiced the art of vinegar production on a large scale, it can be assumed that everything contained in this little book is true and tested... I have tried not to speak of oxygen, carbon, hydrogen and of other things which are totally foreign to vinegar brewers". It took Döbereiner 8 years, after mentioning these 3 chemical elements, to assemble their symbols properly together to write the equation of the acetous fermentation mentioned above.

One explanation for Döbereiner's poor appreciation of chemical knowledge of vinegar brewers could be as follows. In 1826, at that same period, Weinlig wrote: "In France, when someone wants to dissimulate something there is a saying: "c'est le secret du vinaigrier?" (in French in the German text: is it the vinegar brewer's secret?) (Bourgeois 1999). Some modern vinegar brewers are still secretive. But we can reassure Döbereiner that oxygen, carbon and hydrogen are no longer "totally foreign" to them. Döbereiner described the mother of vinegar as a "fungoid growth".

Louis Pasteur (1822-1895)

Pasteur (Fig. 4A) was born in the same auspicious year (1822) as that of the discovery of the chemical equation by Döbereiner, and of the afore naming of *Mycoderma* by Persoon. Pasteur quotes *Mycoderma* in "Etudes sur le vinaigre (1868). It is interesting that Pasteur would have been informed about the discoveries of these two leading scientists, Döbereiner (Fig. 3A) and Persoon (Fig. 2B).

J.L. Shimwell (1961) wrote to commemorate the centenary of the first communication by Pasteur on ace-

Fig. 3. Famous chemist.
A) J.W. Döbereiner (1780-1849) (source: Wüstenfeld H. 1930). B) Anleitung zur kunstmässigen Bereitung verschiedener Arten Essige, Jena 1819.

tous fermentation: "It was not until 1861 that Louis Pasteur made the momentous announcement that vinegar was not made by a purely chemical oxidation of ethanol, but by the agency of a minute living "plant" belonging to the group *Mycoderma.* But it seems that it was not until the next year (1862) that he definitively named it *Mycoderma aceti*. Shimwell was right not to be too affirmative about the date (1862), because Pasteur had already mentioned *Mycoderma aceti* in 1861 in his patent "For the fabrication of acetic acid" (see later).

Finally the real mechanism of vinegar elaboration was only understood when Pasteur published in 1864 (see Pasteur Vallery-Radot 1924) his famous memoir on acetous fermentation. Louis Pasteur identified scientifically the five criteria indispensable for the production of vinegar: 1) alcohol: in wine, cider or other alcoholic beverages, 2) oxygen: that of air, 3) the ferment: *Mycoderma aceti*, a micro-organism of a thousandth of millimeter, 4) the nutrients: such as sugar and proteins naturally present in wine, enhancing the growth of the bacteria, 5) the temperature: between 20 and 35°C.

In 2011, we will celebrate the third Jubilee of the discovery of the mechanism of acetous fermentation by Louis Pasteur.

Martinus Willem Beijerinck (1851-1931)

Beijerinck was one of the founders of modern microbiology. However he was overshadowed by both Pasteur and Koch, because he did not deal with the bacteriology of human beings, as did his two famous contemporaries. Beijerinck was the first to call the acetic acid bacteria *Acetobacter aceti*, in 1898 (111 years ago). In 1897, Beijerinck warned against the "pulverization of species, from which bacteriology suffers so much nowadays". He mentioned 4 species of acetic acid bacteria, and was prophetic when he foresaw that it would be ten times more in the future, or an even bigger number: to date there are 59 species. Shimwell in 1961 reduced this number to two distinct species taking into account mutations.

Emile Claudon

Only seven years after the publication of Pasteur's book, Claudon (1875) wrote a book in honour of the work of Pasteur. He described a vinegar production installation inspired by Pasteur (Fig. 5E). It consisted of 5 columns of 5 flat superimposed vats. The vat with a capacity of 6000 L received the daily production of 5000 L, which was pasteurized in the heating system, and was then ready for sale. Claudon is mentioned in the well documented chapter about vinegar in the classical 20th century Larousse.

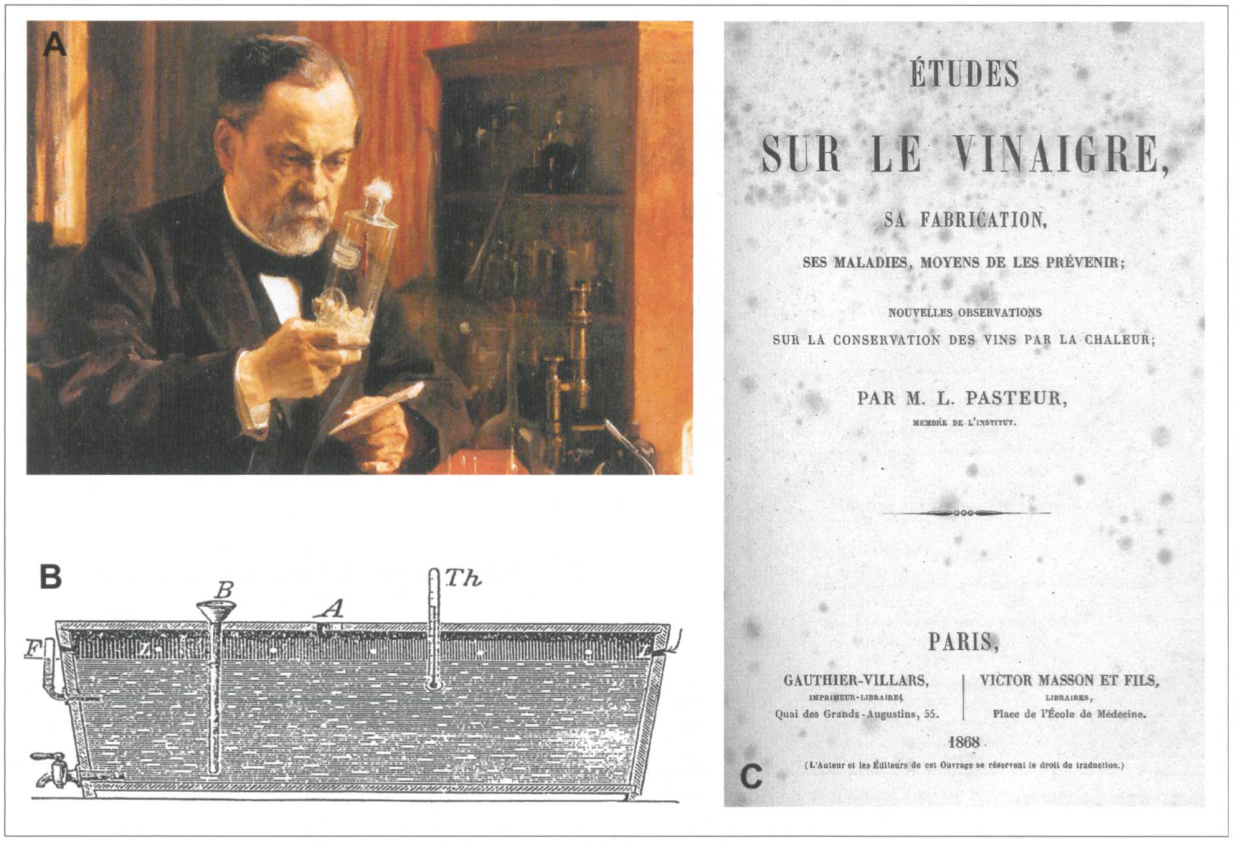


Fig. 4: Famous microbiologist.
A) Louis Pasteur (1822-1895) (source: Lefebvre C. 2000, with kind permission). B) Flat vat of Pasteur: thermometer (Th); funnel (B); vent holes (L); liquid level (F); cover (A). C) Etudes sur le vinaigre (1868) (source: Bourgeois J.F. 1999).

D. Rojat

Rojat was inspired by Boerhaave, 200 years after the developement of his automatic acetification system. Rojat (1895) acknowledged this in the title of his book: "Vinegar fabrication, derived from a combination of the German and Luxemburger methods". The mash was pumped from one sandstone vat to the next one (Fig. 5A).

Toshinobu Asai (1902-1975)

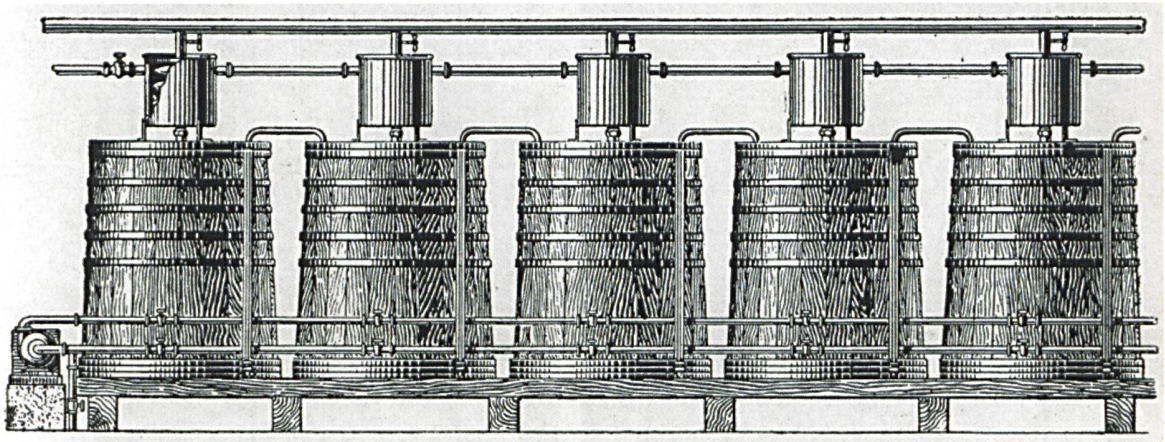
In 1935 Asai (see 1968), a Japanese microbiologist, described a new genus *Gluconobacter*. Numerous names of species were attributed to it later. In fact, the taxonomy of acetic acid bacteria has undergone many changes during the last 30 years: first arranged according to their morphology and their biochemical characteristics acetic acid bacteria (AAB) are now classified in a consensual way, according to the results of various analyses, combining phenotypical, chimiotaxonomical, biochemical and molecular criteria. In the present acetic acid bacteria (Fig. 6) belong to the phylum *Proteobacteria*; class of *Alphaproteobacteria*; in the order of *Rhodospirillales* and the family of *Acetobacteracea*, which comprises, along with 12 genera, 59 species (Yamada and Yukphan 2008; Cleenwerck et al. 2008; Kommanee et al. 2010; Yukphan et al. 2010a,b).

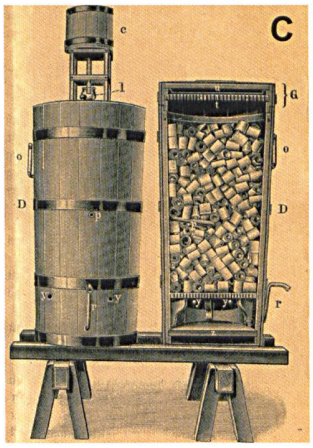
Acetification systems

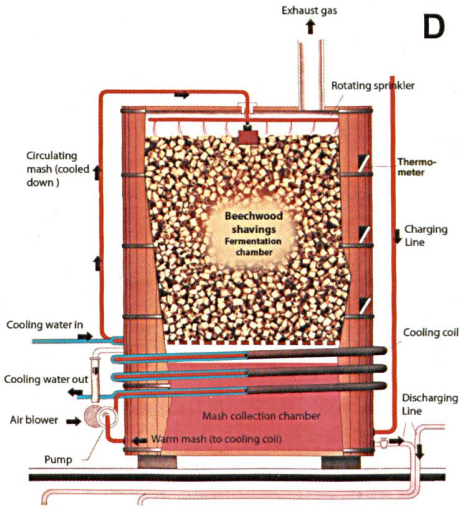
Mother of vinegar system also called Orléans or French

Orléans was a big port on the longest French river, the Loire. A lot of wines arrived there coming from all the regions of France. Often the wines suffered during their transportation turning sour en route. They were sold to the vinegar brewers of Orléans, instead of being sent to Paris, their destination.

In the times of Pasteur there were about 70 vinegar breweries in Orléans whereas today only one is left. Dessaux (Fig. 7B) right up to the 20th century was the biggest vinegar factory in France, Algeria, Morocco and Tunisia. Different Orléans acetifiers are shown in Figure 7, using vinegar mothers. Pasteur summarizes the mechanism of such acetifiers in his request for a patent dated December 9th and 12th 1861, entitled: "For the fabrication of acetic acid". Pasteur describes the necessary installation, still used in households, and even industrially in certain countries: "The process consists of growing these







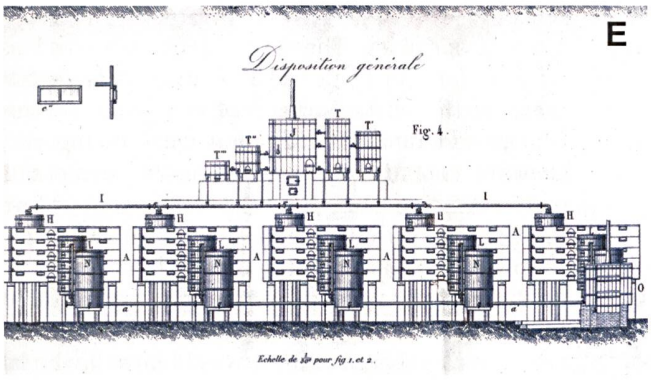


Fig. 5: A) Generators with wood shavings. Continuous acetification system, according to Boerhaave, with automatic sprinkling. (see Wüstenfeld H. 1930). B) beechwood shavings (source: Lefebvre C. 2000, with kind permission of L. Maréchaux). C) small scale model: thermometer (o); rotating sprinkler (g); aeration vents (y) (source: Behrend W. Private collection of Bourgeois J.F.). D) Frings generator (source: with kind permission of Frings/Bonn). E) Emile Claudon acetifier & pasteurizer: 5 columns (n) and superposed vats (a); vat for daily production (o); feeding vats for wine (h); vat for pasteurization (j); filters (t,t`,t``,t```) (Claudon E. Private collection of Bourgeois J.F.).

plants (*Mycoderma aceti)* on a big surface, fed with organic liquids, containing principally phosphates and nitrogenous substances, and to put them into contact with the alcoholic mash to be acetified, in the presence of atmospheric oxygen (...), the alcoholic mash is placed in big vats, not very deep, 10 cm more or less. The plants are seeded on the surface of the liquid, and the vat is either covered with an identical vat, or an ordinary cover. The plant multiplies with extreme speed, and completely acetifies the mash". No wonder Pasteur wanted to patent his system, but he did not do so. He wrote: "I have decided from today to drop this patent into the public domain", which is a mark of his generosity.

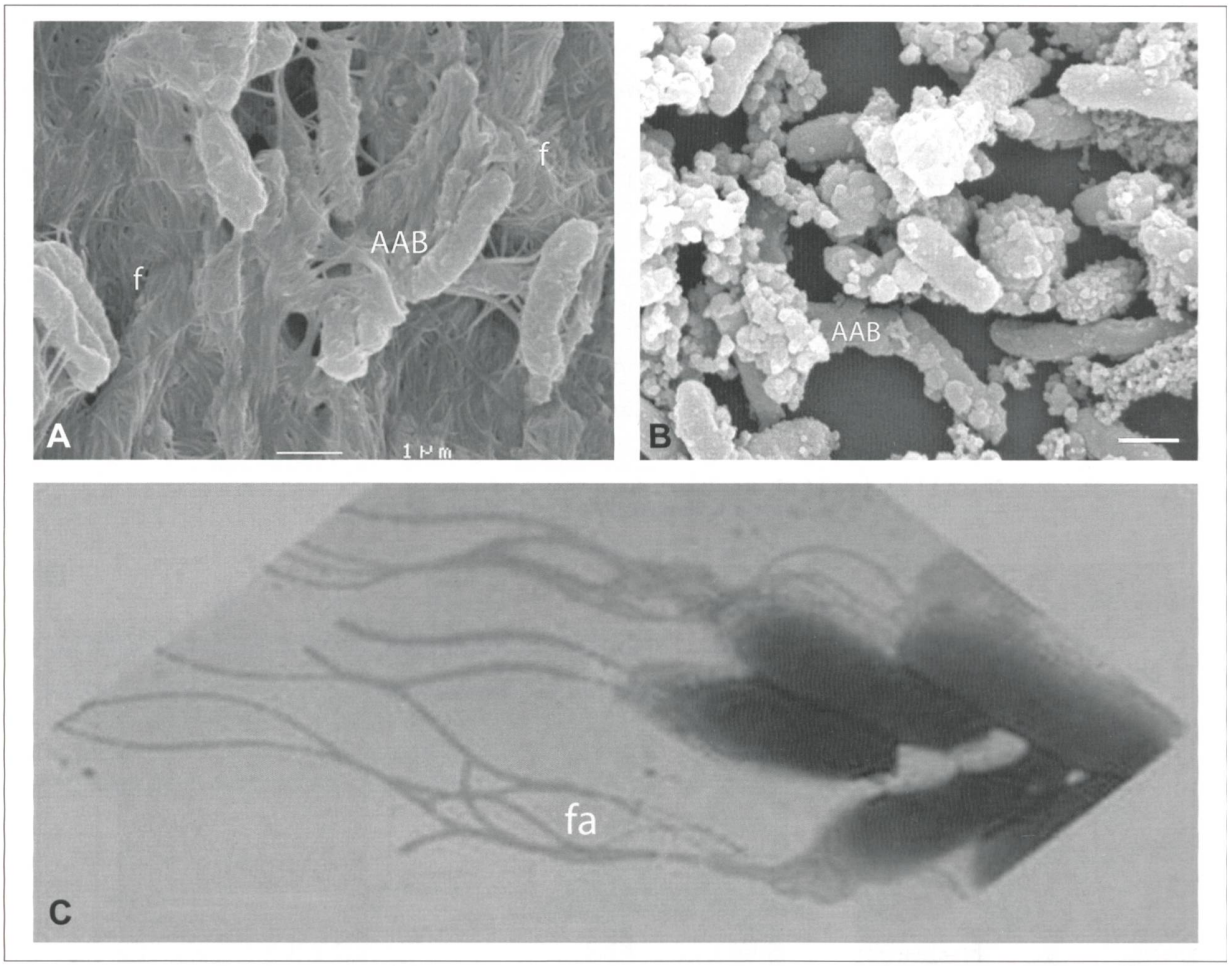


Fig. 6: Electron micrographs of acetic acid bacteria.
A) Scanning electron micrograph of vinegar mother showing cellulose fibers (f) and acetic acid bacteria (AAB). B) Scanning electron micrograph of acetic acid bacteria from submerged vinegar production. C) Negative staining of acetic acid bacteria showing polar flagella (fa) (bar: 1 µm).

Pasteur also showed that the oxidation of ethanol to acetic acid by *Mycoderma aceti* involved an uptake of atmospheric oxygen. Pasteur's flat vat (Fig. 4B) with a surface of 1 square metre, 20 cm high, with a capacity of 150-180 L produced 10-12 liters of vinegar at 5-6% acidity per day. Pasteur foresaw the continuous fermentation process and also the high strength system, both made possible nowadays with the submerged system and computerization.

German rapid acetification system

In contrast to the Orléans system, also called the French system (Contassot 1942), the acetification system industrialized by Schüzenbach (1793-1869, Fig. 2C) was named German.

It was also called "Rundpump" (round pump), because the wood shavings (Fig. 5B) were continuously sprinkled with the mash by a circulation pump, and a rotating sprinkler. The wood shavings served as a support for the bacteria. The acetic acid bacteria grew on the whole surface of the spiral, or scroll, which increased the oxidation surface. Figure 5D shows a cooling coil which kept the fermentation temperature constant, as it differed at various levels, which explains the presence of 3 thermometers. The air blower blew a countercurrent from below. The production capacity at 10% acidity was 70000 – 1000000 L/year, depending on the size of the acetifier, also called generator. It was Shimwell who later called the generator with wood shavings the "trickly", because of the sprinkling system. In the demonstration model there are natural air drafts (Fig. 5C). The maximum life span of shavings is half a century.

More than two centuries after Schüzenbach, wood shavings are still in use. Alternative materials like bines, maize cobs, or rushes are cheaper than beechwood, but not as efficient.

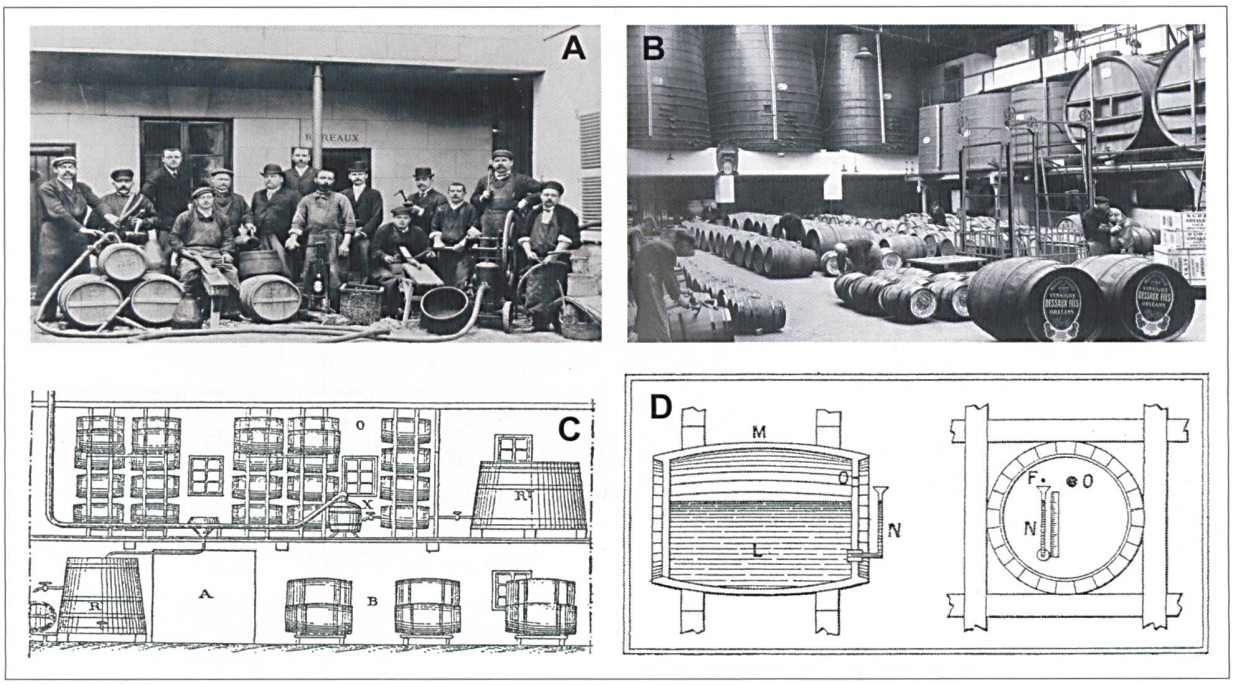


Fig. 7: Different Orléans acetifiers based on vinegar mothers and pictures of Orléans vinegar breweries from the past. A) Vinegar brewers and their tools, Orléans, 1897. B) Dessaux Fils vinegar brewery in 1950 (source: Lefebvre C. with kind permission). C) General view of "vaisseaux orléanais": Orléans barrels, 230 L (O); entrance door to store room for wine (A); stove (X); vats for fining of wine and vinegar (R, R'). D) barrel details: vent peg (F); mash (L); liquid level (N); vent hole (O); monture = barrel (M) (source: Bourgeois J.F. 1999) .

Pasteur, in his book "Etudes sur le vinaigre et sur le vin" (cited by Pasteur Vallery-Radot 1924), wrote about the two methods: "The German system is very popular nowadays. It is a process with wood shavings, together with the Orléans system, which is very old and already used in the past century in Orléans, and even in Paris" (Fig. 5A-D).

Rotation acetifier systems

We now come to rotation acetifiers which do not exist any more, probably because the mechanism was too delicate and subject to corrosion. But the history of their existence during the 20th century is interesting to consider.

In the previous generator systems the vats were fixed, and the mash mobile. On the contrary, with the rotation systems the vats were mobile. The barrels had a capacity of 600 L, filled with wood shavings, as well as 2 wickerwork air ducts (see Fig. 8A,C). Cogwheels assured that each barrel rotated a complete turn (which took a minute). This rotation was repeated on average 6 times/day. During the operation the holes had to be blocked. G. Haeseler noted in "Ullmann's Encyclopedia" (1955) that this rotation system was used mainly in France and Switzerland (see later Simplex system).

The Figure 8B shows the "Electro-Aceto". It is an interesting word combination. The relatively new invention of the electric motor made the automation of the rotation acetifier possible, in the 19th century, with its "fully automatic functioning" rotation acetifier "Electro-Aceto" by Ménégault.

Swiss acetifiers

A congress about acetic acid bacteria was held in Japan in 2008. The Japanese honour their ancestors. So it was easy for one writer of these lines, the last of 3 generations of Bourgeois vinegar brewers, to speak of his grandfather Isaac, and father Charles, in connection with their acetification systems.

Isaac Bourgeois (1871-1926) (Fig. 9A) was the inventor of "Simplex", and founder of the Bourgeois vinegar and mustard factory, about 100 years ago (Fig. 9C) in Ballaigues (Fig. 9D). I. Bourgeois called his own rotation system "Simplex" (Fig. 8D) because, according to him it was easy to produce vinegar by "just analyzing the acidity and the alcohol content". I. Bourgeois received gold and silver medals for "Simplex" at Italian exhibitions.

In the historical review "Die deutsche Essigindustrie", Wüstenfeld and Föhr (1913) wrote an article about

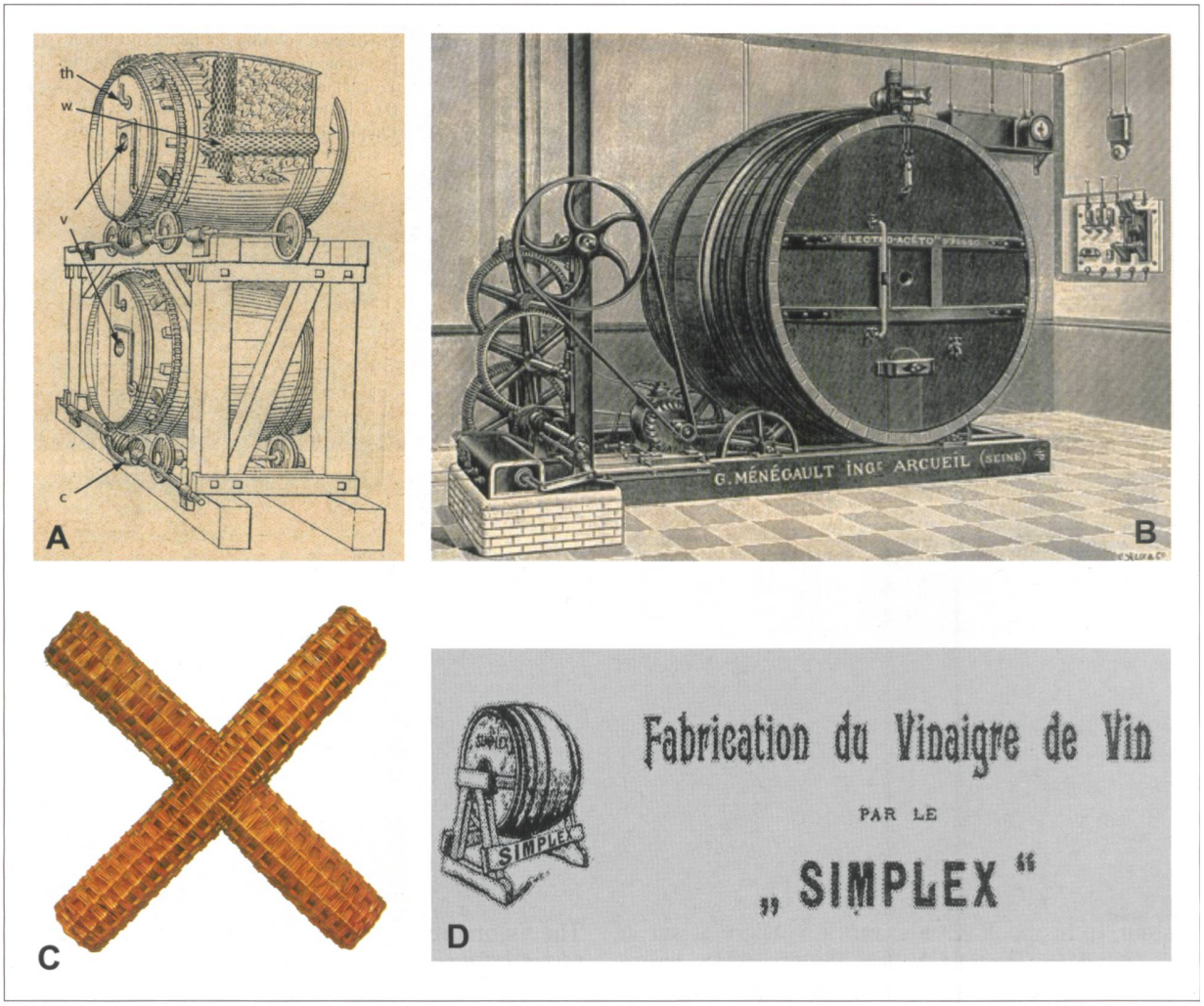


Fig. 8: Rotation acetifier systems.
A) Barrels of 600 L, filled with wood shavings: wickerwork airducts (w); cogwheels for rotation (c); thermometer (th); vent holes (v) (source: Franche 1914, with kind permission of J.F. Bourgeois); B) Ménégault rotation system (source: Fritsch 1923, Private collection of Bourgeois J.F.), with electrical motor; C) Wickerwork airducts (with kind permission of vinegar factory Jolly near Paris); D) Simplex acetifier, built by I. Bourgeois: rotating barrel 1.5 m x 1.2 m, with shavings inside and air vent.

Simplex called "Versuche mit einem Drehessigbildner", ("Tests with a rotation acetifier"). They wrote: "Advantages of the system: excellent efficiency, low evaporation loss".

I. Bourgeois was the first to produce whey vinegar industrially 100 years ago. It was manufactured under license in France and Austria under the trade mark "Lactavinegar".

Charles Bourgeois (Fig. 9B) (1901-1958), the inventor of the "Acetomatic" which was installed in Bingen/Rhine, Germany, among the other places (Fig. 10A). Thanks to the 2 vats, each one discharged every other day, all the alcohol was transformed into acetic acid, giving better efficiency. Twenty "Acetomatics" were installed up to 1980 with the daily production of 5000 L of vinegar at 10% acidity. C. Bourgeois first mentioned his submerged acetification system "Acetomatic", in the French review "Bulletin Technique de la Vinaigrerie", in 1950: "It is obvious that the ideal acetification system will, optimally, use the totality of the input of oxygen, producing a minimum of CO_2. According to our research we can say that we approach these 2 ideal conditions with the submerged system" (Bourgeois 1950). At the same period, Hromatka and Ebner (1949, 1950, 1951), Hromatka et al. (1951, 1953), Hromatka and Exner (1962), Hromatka and Polesofsky (1962a,b) wrote the classical publications about the submerged acetification system. Shimwell called this method the "bubbly", to distinguish it from afore mentioned "trickly", the name given to the generator system with the wood shavings.

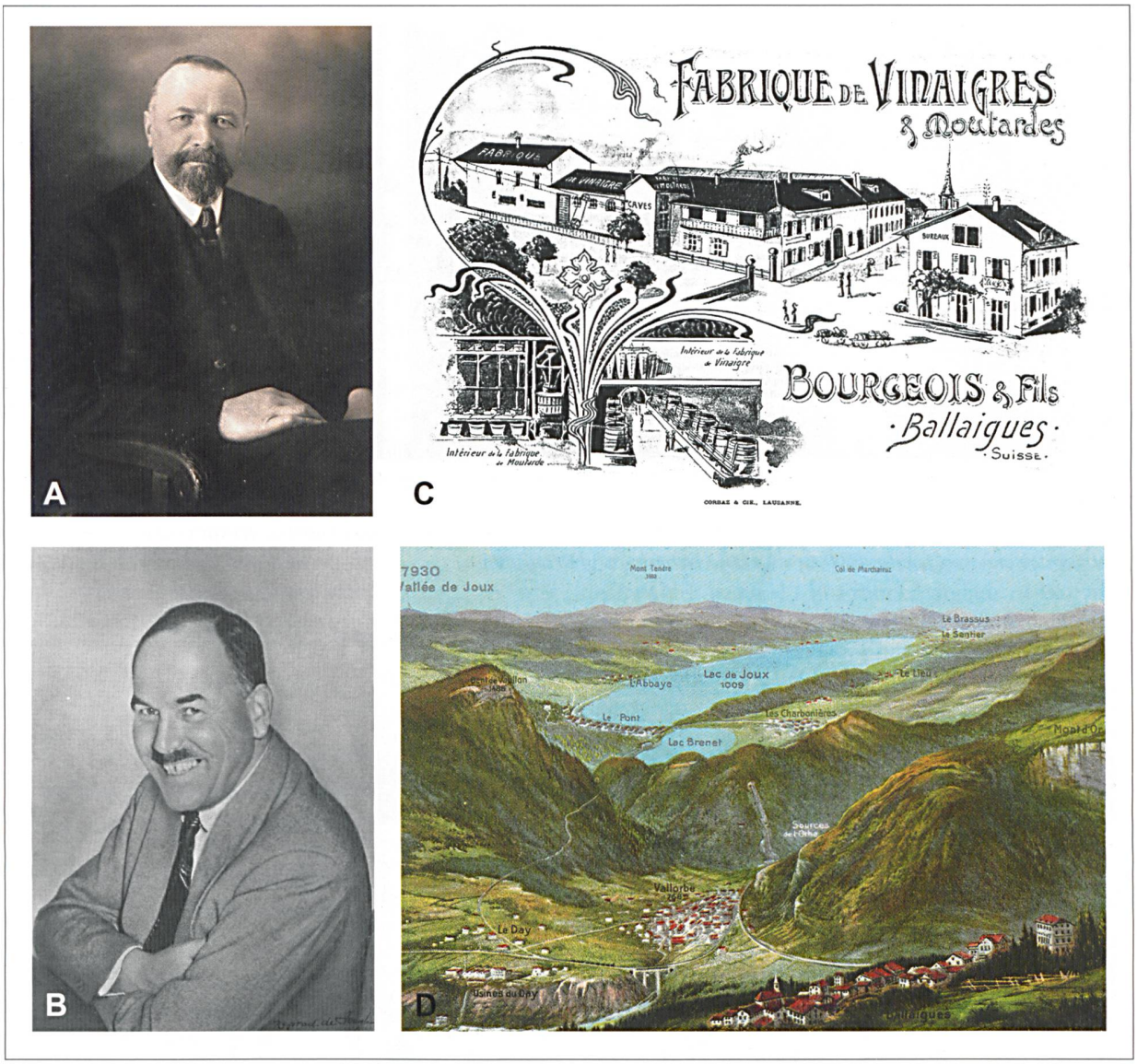


Fig. 9: Bourgeois Family saga.
A) Isaac Bourgeois (1871-1926). B) Charles Bourgeois (1901-1958). C) Vinegar and mustard factory founded by I. Bourgeois, beginning of 20th century. D) Ballaigues, lower right, birth place of three generations of vinegar brewers (private collection Bourgeois J.F.).

The Acetator

All the previous traditional acetifiers were superseded by advances in technology, thanks to the submerged fermentation process, used firstly for the production of antibiotics, and then subsequently thanks to computerization. The Acetator is a good example of this advance in technology. Figure 10B shows 2 Acetators in the pilot plant of Frings in Bonn. Annual production is half a million litres of vinegar at 10% acidity.

Asian acetifiers

We now leave Europe for Asia, where the production of vinegar is an old tradition, first considering the Chinese methods of acetification, and then the Japanese. The word for vinegar written in Chinese is tsu (Fig. 11B). The Chinese produce vinegar from maize, millet, corn, sorgho, rice and sweet potatoes. Apart from traditional acetification methods, the Chinese also use the submerged system.

The Figure 11A shows a picture of a Japanese vinegar brewery, 18th century. Pails and flat wooden vats were used.

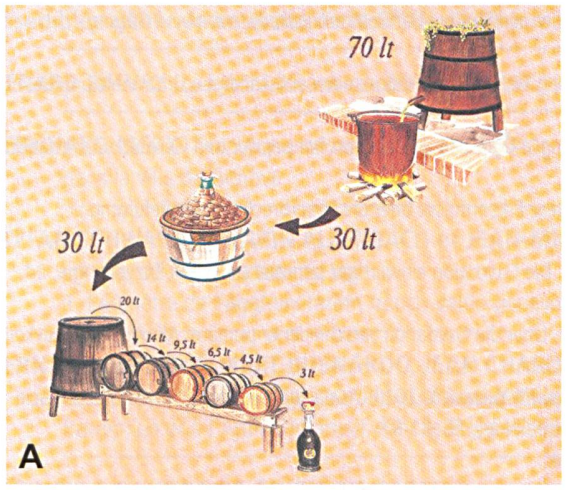
Traditional Balsamic vinegar method

Now we come to the production of balsamic vinegar, rooted in a family tradition originally evolved in a small region in the North East of Italy. It is the slowest acetification system, as it requires a minimum of 12 years before use. The acetification and alcoholic pro-

Fig. 10: Submerged acetification systems.
A) Acetomatic acetifier built by Ch. Bourgeois, installed in Bingen/Rhine: 2 wooden vats of 6000 L. B) Vat in the foreground, pilot plant Acetator, capacity: 1200 L (with kind permission of Frings/Bonn).

Fig. 11: Asian vinegar plants.
A) Japanese brewery 18th century with pails and flat wooden vats (with kind permission of Vinegar Museum Mizkan, Nagoya Japan). B) Old Chinese system. In the red circle, word vinegar in Chinese: tsu.

cess begins with 70 L of grape juice, which are reduced to a concentrate of 30 litres by cooking (Bellocchi 1991; Lambert 2010). This concentrate is then poured into a demijohn, and left to decant over the winter. In spring the fermentation begins, and grape-juice concentrate is poured into the first wooden barrel, where yeasts start the alcoholic fermentation. In the summer the acetic acid bacteria (mother of vinegar) start the vinegar fermentation. At this point 20 L are decanted from this large barrel into the first of a diminishing series of 5 barrels, each of a different wood type. Over the next 12 years, the liquid will evaporate at an average 10%/year. The level of each barrel will be maintained at two-thirds of their capacity by a process of topping up from the preceding barrel (Fig. 12). In the 13th year of this aging process, 3 L of mature vinegar is siphoned off (a maximum of 20% of the liquid contained in the last small barrel). The following year, cyclically, another 3 L will be ready to be siphoned off.



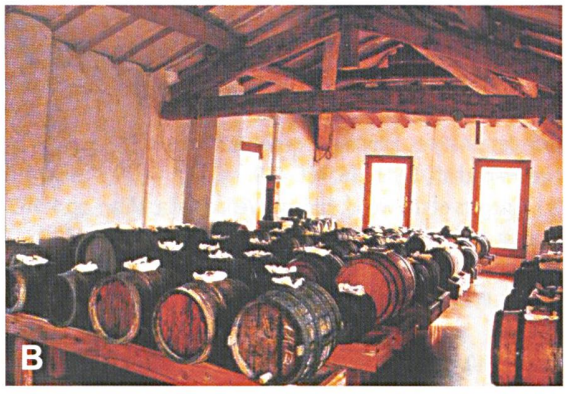


Fig. 12: Famous balsamic vinegar.
A) Elaboration process of traditional balsamic vinegar, Modena region (source: Bellocchi 1991, Fig. p. 27). B) "Acetaia", vinegar production in attic (source: Bellocchi 1991, with kind permission of Consorzio Tutela Aceto balsamico tradizionale di Reggio Emilia).

On the market there is a much cheaper sort of balsamic vinegar different from the traditional one. It consists mainly of wine vinegar, grape juice concentrate and caramel.

Various sorts of vinegars

It was mentioned previously that Döbereiner quoted 16 "substances" which can be transformed into vinegar either: 1) directly from fruits such as grapes, apples, pears, cherries, prunes, gooseberries, currants, raspberries, lilac, elder flower, chestnuts, bananas or from vegetables: sugar beets, mangel wurzels, carrots, potatoes (Solieri and Giudici 2009); 2) after hydrolysis of starch into glucose and maltose (Grierson 2009).
Lefebvre (2000) mentioned 110 different vinegars. Bibliographical sources quote therapeutic, hygienic, prophylactic, medicinal, cosmetic and detergent vinegars. Now there are even vinegars which have a designated origin: 1) in France: vinegar of Banyuls, Châteauneuf du Pape, 2) in Italy: Aceto balsamico tradizionale from Reggio Emilia and Modena (described previously) (Lambert 2010), and 3) in Spain: Sherry vinegar (Tesfaye et al. 2009).

Conclusion

Acetic acid bacteria are the quiet "slaves" of vinegar brewers. They deserve our special attention; they need a continuous supply of oxygen, constant temperature, nutrients in the form of glucose, vitamins and amino acids, etc.
It is interesting to notice the enormous increase of different varieties of vinegar in the last 200 years. Döbereiner mentioned 16, and Lefebvre 110. According to Ebner and Follmann (1983): "There is no doubt that the production of vinegar is among the highest for a product of primary microbial metabolism".

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