ROCA-ROSELL, A. (ed.).(2012) *The Circulation of Science and Technology: Proceedings of the 4th International Conference of the ESHS, Barcelona, 18-20 November 2010.* Barcelona: SCHCT-IEC, p. 441.

MAKING SCIENCE COOLER: CARRÉ'S APPARATUS

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Abstract

The need of refrigeration in the laboratory is not a new idea, and this paper intends to make a tour through its history in the 19th century, where one of the first attempts to make things cooler was created by the Carré brothers. The aim is to explore the types of Carré Apparatus and the techniques used in it, and to study their evolution and improvement. This work will focus mostly in the instrument's collection of the Museum of Science of the University of Lisbon, which owns several exemplars of the Carré Apparatus as well as improved versions of it. Our approach tries to put these objects back in their real place in the 19th century lab work, corroborating equipment with archival sources by establishing links between equipment and photographs, reports, curricula, chemistry compendia, textbooks written by the professors, where certain experimental settings are described and depicted, invoices and other administration papers, e.g. the 1854 inventory, among other archival and bibliographical sources. The 19th century 'Laboratorio Chimico' *of the Polytechnic School (1837-1911), integrated in the Museum of Science of the University of Lisbon suffered a restoration and a musealization work (1998-2007) as well as a part of the museum's heritage, where a Ferdinand Carré's apparatus is included. This historical space and the pertaining collection allows us to go back to the 19th century scientific practice at the Lisbon Polytechnic School and breathe its atmosphere in a golden period.*

Artificial production of ice

In the 16th century, the discovery of chemical refrigeration was one of the first steps toward artificial means of refrigeration. The first attempt to artificial production of ice was implemented by Lahire in 1685: he produced ice by wrapping wet ammonia salt and a jar full of water, already cooled (Figuier; 1873). The first machines used in the mechanical production of cold were constructed on the principle of the vacuum machine, wherein the vacuum –which was obtained mechanically– permitted the refrigerant to boil at a sufficiently low temperature to secure the results desired. These machines included that of William Cullen (1710-1790), used in 1755 for producing ice using water under high vacuum; the optician and scientific instrument maker Edward Nairne (1726 – 1806) recognized that water vapour is rapidly absorbed if he put a container with water near a pot with sulphuric acid, both closed, inside a pneumatic machine bellflower. Later in 1811, the physicist John Leslie (1766 –1832) obtained water boiling at a low temperature (Leslie; 1813).

Ferdinand Carré's apparatus

In 1856, the French engineer, Ferdinand Philippe Edouard Carré (1824–1900) developed his first refrigeration apparatus using sulphuric ether, with the inconvenience that ether is highly inflammable. Later in 1859, Ferdinand Carré made the first ammonia / water refrigeration machine. The Carré absorption cycle used in this apparatus was an outgrowth of the observation by Michael Faraday (1791–1867) in 1823, which noticed the cooling properties of ammonia closed in a bent glass tube. Ferdinand replaced the ether by ammoniac because of its stability, low boiling point (44º C) and its affinity with water. This absorption machine (figure 1) was patented in France in 1859 and in the U.S.A. in 1860 (Figuier; 1873). The abstraction of heat is made by evaporation of a separate refrigerating agent of volatile nature under the direct action of heat, which agent again enters into solution with a liquid. This is termed the "absorption system" (Greene; 1916). When a body changes its state, a certain amount of energy must be absorbed by that body to bring about this changed state. The name "heat energy", or heat, is applied to this. Energy is required to change a body from the liquid state to the vapour state.

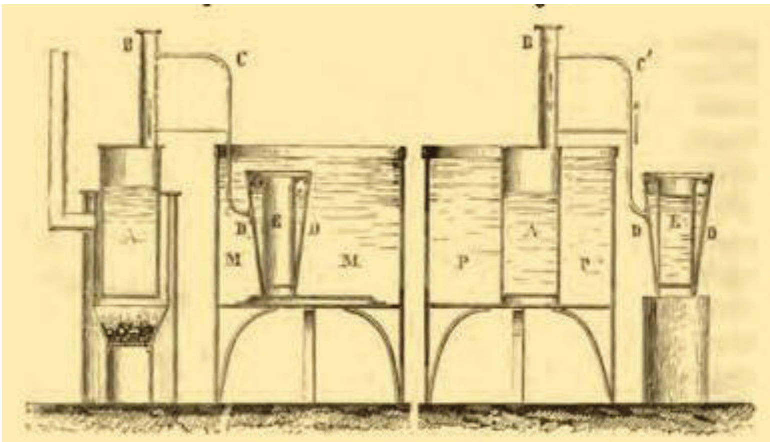

Fig. 1: Engraving representing a Ferdinand Carré's apparatus (Jamin; 1878).

This apparatus consists in two pots hermetically closed, in communication by means of tubes. The largest (A), a cylinder, contains a concentrated ammonia solution (ammoniac gas dissolved in water), which is heated with a furnace. The small one (E), a vessel in the shape of a truncated cone having a cavity in centre, was kept in a trough with water. This refrigerating machine is furnished with a thermometer which doesn't communicate with the interior of cylinder (A).

But how does this apparatus work? The cylinder (A) contains ammoniac gas, dissolved in water. When it is heated, the gas espies from the liquid and passes into a vessel (E), after having passed through all the connecting tubes. But on arriving there it finds no exit, accumulates, and under the influence of cooling and considerable pressure, becomes liquefied. This is the moment when the generating cylinder (A) is plunged into a cold water container and consequently cooled. The gas which is liquefied in vessel (E) returns to a gaseous state, a corresponding absorption of heat accompanies this change, and the water dissolves once more the ammoniac gas and the primitive ammoniac aqueous solution formed (in A). Soon it is possible to take from the cavity a block of ice (Tissandier; 1867).

Ferdinand apparatus had great advantages: ice could thus be produced using small portions of coal; its small dimensions prevented the production of large quantities of ice at once. But it could not be made to work continuously, and could never be of much industrial value. Another apparatus (figure 2), however, had been invented by him, constructed on a much larger scale, and had successfully solved the important problem of the artificial manufacture of ice or the production of cold.

A large boiler (A) contains the solution of ammonia. The gas escapes and becomes liquefied in a reservoir (B), cooled off as it is by the water which falls from a reservoir (C). The liquid ammonia penetrates into the hollow sides of the refrigerator (G), which contains cylinders filled with the water that is to be frozen. During this time an especial arrangement allows this waste water of the boilers to penetrate, after having cooled off, into a vessel (E) connected with the cylinder (D), in which the ammonia is distilled that has been volatilized in the refrigerator. The original liquid, thus regenerated, is conveyed into the boiler by means of a pump (F). This apparatus acts with great regularity, and it is astonishing to see large blocks of ice issuing from this refrigerator, which are formed as if by magic, without any visible agent to show the secret of their formation.

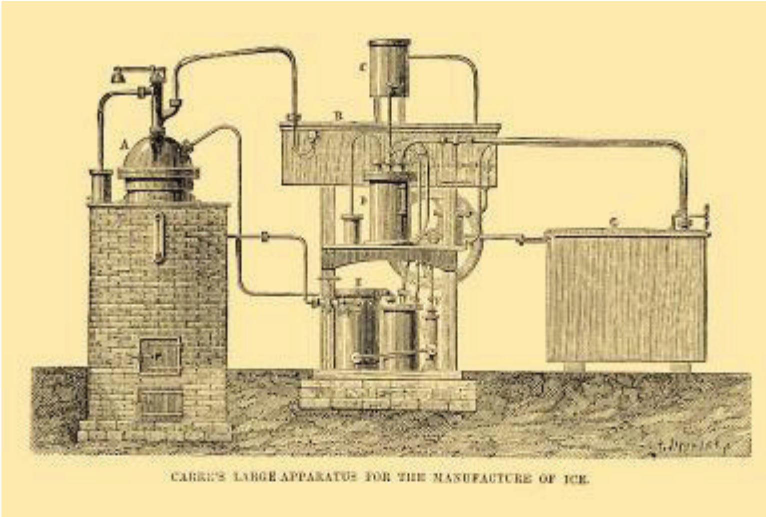

Fig. 2: Engraving representing a Ferdinand Carré industrial apparatus (Tissandier; 1867).

In 1862 Ferdinand Carré exhibited his ice-making machine at the Universal London Exhibition, producing an output of 200 kg/h (Figuier; 1873). Its design was based on the gas-vapour system. Ferdinand's industrial apparatus had the great advantage of allowing a continuous ice production.

Edmond Carré's apparatus

In 1811 John Leslie described a laboratory method of making ice by freezing water in a saucer placed in a receiver under vacuum –the water vapour, as it boiled off under low pressure maintained in the receiver, is absorbed by sulphuric acid in another saucer (Leslie; 1813). In the case of the vaporization of a liquid under reduced pressure, the aim of this reduction is to allow the evaporation at such a low temperature that heat may be removed from surrounding objects of low temperatures. When the pressure was reduced, the boiling temperature would decrease and with the evaporation of some liquid, ice could form. Leslie improved this machine later into a pneumatic machine, under the principle that the abstraction of heat is effected by the evaporation of a portion of the liquid to be cooled, the process being assisted by an air pump (Macintire, 1928). This is known as a vacuum system.

In 1866 Edmond Carré (1833-1894), Ferdinand's brother, repeated the Leslie experiment and found that it was necessary a larger quantity of sulphuric acid for a small quantity of water. At the same year, Edmond adapted the Leslie process to a pneumatic machine and added an agitator to renew the surface of sulphuric acid and increase the surface area in contact with water vapour and thus improve the capacity of sulphuric acid to absorb it. He obtained a bigger efficiency, allowing the production of greater quantities of ice (Jamin; 1878). Water is placed in a bottle that adapts to a tube, which will give a bath of sulphuric acid, continually being shaken with an agitator (figure 3).

This apparatus consists of a pneumatic pump (P) and a large tank (R). The sulphuric acid is introduced in the tank (R), which is in communication with the pneumatic pump (P) through the tube (b) and in communication either with the bottle of water through the tube (h) and the tap (r). The lever (M), which gives movement to the stem of the piston of the pneumatic pump, moves through the stalk (t) an agitator, which constantly renews the surface of the acid.

The Edmond's apparatus great advantage (Vidal; 1893) was that in three minutes the water temperature decreases to the freezing point and ice is produced.

Refrigeration apparatus in the Polytechnic School of Lisbon

The Polytechnic School of Lisbon was a landmark in Portugal because it was one of the few schools where chemistry was taught. It was founded in 1837 in order to prepare students for the Army and Navy schools, while offering access to higher science education for students of other professions, medicine and pharmacy. In accordance with the foundational document, the School was to be provided with a Library, an Astronomical Observatory, a Cabinet of Physics, a Chemical Laboratory, a Natural History Cabinet, a Botanical Garden and other common facilities. The disciplines were organized and taught in five courses. The *6ª Cadeira* –denominated 'General Chemistry and Principles of its Applications to the manufactures'– was usually lectured in the second year of most of the courses (Elvas; 2009). An additional discipline was created in 1859: Chemical Analysis and Organic Chemistry.

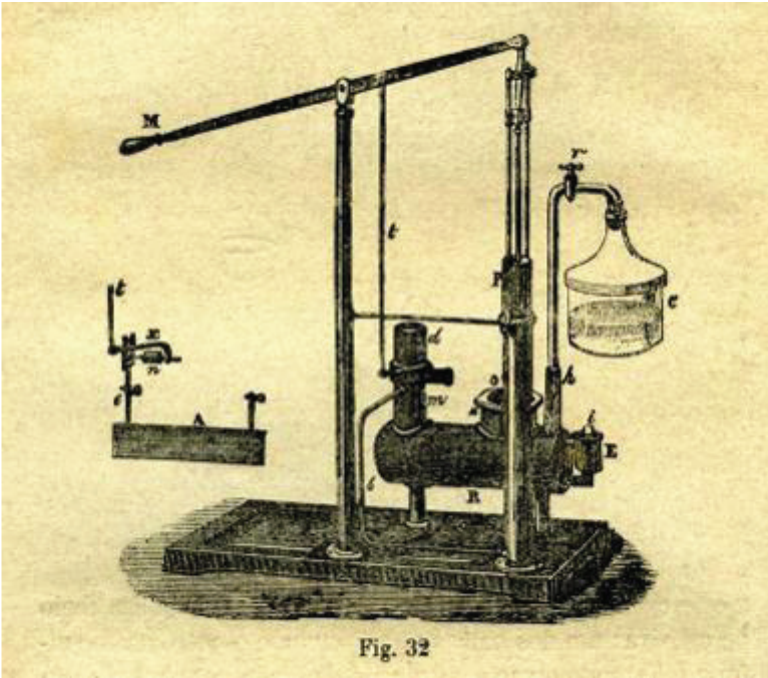

Fig. 3: Engraving representing an Edmond Carré's machine (Vidal; 1893).

Júlio Máximo de Oliveira Pimentel (1809-1884), the first Chemistry Professor of the Polytechnic School of Lisbon (between 1837 and 1864), mentioned on his chemical lesson's book chemical reactions where ice was used, for example, the hydrocyanic acid synthesis, the sulphurous acid synthesis and the hydrogen fluoride synthesis (figure 4). Adriano Augusto de Pina Vidal was a Physics Professor of the Polytechnic School of Lisbon (Vidal; 1893). He referred on the physical lesson's book the Ferdinand Carré and the Edmond Carré machines and there he described the mechanism of these machines.

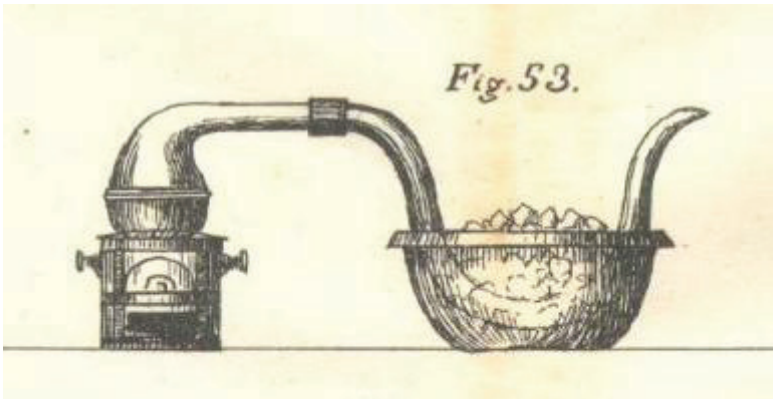

Fig. 4: Engraving representing the hydrogen fluoride synthesis (Pimentel; 1850).

Refrigeration apparatus in MCUL

As a case study we present the apparatus that belonged to the Polytechnic School of Lisbon. At the time there were a *Laboratorio Chimico* and a lecture theatre that is now part of the Museum of Science of the University of Lisbon's heritage. In parallel with these spaces, MCUL hosts a Historical Archive and a Cultural Heritage where Carré's apparatus are included.

The Museum of Science of the University of Lisbon's Historical Archive encloses documents concerning the icemaker apparatus acquisition, such as:[1]

- An account of expenditure for the *5ª Cadeira* of the Polytechnic School of Lisbon (1863) where we can read *'Ice maker apparatus' acquisition'*;
- An Invoice for the *6ª Cadeira* of the Polytechnic School of Lisbon (1869) which refers a *'Carré's apparatus acquisition'*;
- An account of expenditure for the *6ª Cadeira* of the Polytechnic School of Lisbon (1883) where we can see *'Remediation of a piece of ice apparatus'*

The Museum of Science of the University of Lisbon has three refrigeration domestic devices in its collection:

1. A refrigeration appliance which belonged to the Portuguese royalty –consists on a pneumatic machine for Leslie Experiments (MCUL153) (figure 5).
2. Ferdinand Carré's apparatus (MCUL 2035), actually displayed on the *Laboratorio Chimico*, the 19th historical space that belonged to the Polytechnic School of Lisbon (1837-1911) (figure 6).
3. An Edmond Carré's apparatus (MCUL 4294) (figure 7).

Fig. 5: Pneumatic machine for Leslie Experiments, MCUL153
(Photo: S. Carvalho, Courtesy Museum of Science, University of Lisbon)

[1] MCUL Historical Archive, University of Lisbon.

Fig. 6: *Laboratorio Chimico*
(Photo: M. C. Elvas, Courtesy Museum of Science, University of Lisbon)

Fig. 7: Edmond Carré's apparatus, MCUL 4294
(Photo: M. Peres, Courtesy Museum of Science, University of Lisbon)

Laboratorio Chimico and the lecture theatre of the Polytechnic School that are now part of the Museum of Science of the University of Lisbon's heritage suffered a restoration work between 1998 and 2007. The *Laboratorio Chimico* and its collection provide an excellent opportunity to look into the conditions of scientific practice of chemistry at the *Laboratorio Chimico* by the end of the 19th century. The restoration project of the *Laboratorio Chimico* included the restoration of a part of the Museum's chemistry collection. Ferdinand apparatus was one of those and it is displayed in the *Laboratorio Chimico* (figures 8 and 9).

Figs. 8 and 9: Ferdinand Carré's apparatus, before and after restoration, MCUL 2035
(Photos: M. C. Elvas, Courtesy Museum of Science, University of Lisbon)

The Ferdinand Carré's apparatus and its restoration was one of the several selected objects and results of a study which corroborates equipment with archival sources by establishing links between the collection and photographs, correspondence, reports, curricula, chemistry compendia, among other archival and bibliographical sources. These know-how then supplied the points of departure for further investigation and attempts for answering the following questions:

1. Which of the objects, present in the Museum collection today, were actually part of the *Laboratorio Chimico*? And for how long have they been used?
2. What was the context of their use during that particular period of teaching, research and development at the *Laboratorio Chimico*?
3. Which objects have supposedly been used, but are not to be found anymore in the collection?
4. When, from where and why exactly have they been purchased?

Ferdinand Carré's apparatus belongs to the objects set that could not be located on photographs, but could be identified in other documental sources of the archive, and still is present in the collection. This apparatus appeared on textbooks written by the professors, where certain experimental settings are described and depicted.

Carré´s apparatus: spread out

It was about the middle of the 19th century that the Carré brothers produced commercial machines for the freezing of water. Both machines operated by removing heat by vaporization of a volatile fluid. Edmond Carré's apparatus used the evaporation of water vapour at very low pressures and Ferdinand Carré's used the evaporation of liquid anhydrous ammonia.

The Carré's apparatus appeared in several catalogues of laboratory material of chemistry and physics; schoolbooks; medical, industrial and advertising publications; universal exhibitions and so on. Some examples are a 19th French advert (figure 10) in the *Revue des Instruments de Chirurgie* (1892).

Other Portuguese collections exhibit the Carré's apparatus, for example, the Science Museum of the University of Coimbra owns a Ferdinand Carré's apparatus (figure 11) and an Edmond Carré's apparatus.

From what was told above, the importance of this mechanical refrigeration can be seen, but with its development further applications have been made and used into many industries (Greene, 1916):

- In refining oils, refrigeration is used for the removal of certain paraffin products;
- In metallurgical operations, refrigeration allowed to get air of uniform quality;
- In textiles manufacture, in tobacco curing and cigar making, in perfumery making, in photographic films manufacture and other products.

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Fig. 10: French announce (Courtesy of Paolo Brenni)

Fig. 11: Ferdinand Carré apparatus, QUI 0169
(Photo: Gilberto Pereira Courtesy of Science Museum of University of Coimbra)

Acknowledgements:

We are most thankfully to the following institutions for their support during this research:

- Fundação para a Ciência e Tecnologia
- Science Museum of the University of Coimbra

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