De Re Metallica, 24, 2015 pp. 45-55

ISSN: 1888-8615

EXCHANGE AND TECHNOLOGICAL INNOVATION IN THE WORK OF ANDRÉS MANUEL DEL RÍO[1]

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RESUMEN

Los años de 1770 a 1850, periodo aceptado en la literatura especializada para hablar de la Revolución Industrial, enmarcan la vida y la obra del naturalista y científico Andrés Manuel del Río Fernández (1764-1849). Andrés del Río nació y murio inmerso en el proceso de aprendizaje e innovación tecnológica que trajo consigo la vorágine de ese fenómeno económico e industrial. Aquí se estudia a través de su quehacer la interrelación que se dió entre los procesos de aprendizaje con los cambios habidos en la adaptación o innovación tecnológica entre los individuos que formaron parte del fenómeno universal de la Revolución Industrial. Del análisis de su formación profesional, de la obra escrita y del quehacer técnico-científico que desarrolló en Nueva España/México, se concluye que los procesos de innovación tecnológica fueron en la mayoría de los casos el resultado de aprendizajes tecnológicos individuales con un bajo grado de interacción y complementariedad. Pero Andrés del Río, a diferencia de sus colegas alemanes e ingléses, logró probar que tanto el conocimiento como las innovaciones tecnológicas, su originalidad y eficacia, eran el resultado de un entorno histórico y su contexto cultural que determinaba su progreso.

PALABRAS CLAVE: Revolución industrial, innovación, Andrés del Río, Nueva España, México.

ABSTRACT

The years of 1770-1850, accepted in the literature to discuss the Industrial Revolution period, frame the life and work of naturalist and scientist Andrés Manuel del Río Fernández (1764-1849). Andrés del Rio was born and died immersed in the learning process and technological innovation that brought the turmoil of the economic and industrial phenomenon. Here we study, through his work, the interrelationship between the learning processes, with changes in adaptation and technological innovation among individuals who were part of the universal phenomenon of Industrial *Revolution*. I also present an analysis of his professional training, written and scientific-technical work he developed in New Spain / Mexico. It is possible to conclude that the processes of technological innovation were in most cases the result of individual technological learning with a low degree of interaction and complementarily. But Andres del Rio, unlike their German and English colleagues, was able to prove that both their modeling as the process of technological innovation that materialized in the water pump in the Moran Mine in Real del Monte and Pachuca and the building of the forge in the mountains of the province of Michoacan, their originality and effectiveness, were the result of a historical setting and cultural contexts that determined their progress.

KEY WORDS: Industrial Revolution, innovation, Andrés del Río, New Spain, Mexico.

Recibido: 21 de agosto, 2014 • Aceptado: 9 de marzo, 2015

The year 2014 marked the 250th anniversary of the birth of the famous naturalist Andrés Manuel del Rio, 220 years after his arrival in the territory of New Spain and 165 years after his death in Mexico City. He was born, lived and died immersed in a time of profound changes in all areas of human endeavor: the Scientific Revolution of the sixteenth and seventeenth centuries, who brought new ideas and knowledge in physics, astronomy, biology, medicine and chemistry; the Industrial Revolution of the eighteenth and nineteenth centuries that introduced mechanized serial production; and the French Revolution of 1789 that would change the concept of the citizen subject. Those three events laid the foundations of modern science, capitalist production and the formation of modern states. The life and work of Andrés del Río could not be understood without these components, without those realities that motivated his scientific curiosity and intellectual formation, and out of scholasticism, he would actively participate in innovation processes of science, technology and politics.

In this global scenery it was the naturalists of the eighteenth and nineteenth centuries who undertook the "systematic" recognition of the territories of New Spain and independent Mexico, and those who first formulated bounded descriptions of geographic and ethnographic spaces, particularities of the flora and fauna of particular ecological niches and the nature and structure of their mineral resources. Their scientific practice since the called Natural History would contribute to formulating the foundations of diverse knowledge systems of natural and social reality and processes of socialization of knowledge, through the establishment of educational institutions, associations, museums, libraries, newspapers and magazines (Diaz de Ovando, 1998, vols I, II, III; Morelos Rodríguez, 2012.).

In the history of New Spain exploitation of the most common minerals such as silver, gold, copper and iron, had shown its importance in the development of the colonial economy. The overall vision that first offered the naturalist Alexander Humboldt, on the mineral wealth in his Political Essay on the Kingdom of New Spain, motivated the interest of governments and institutions of education for the statistics and scientific study of minerals: their geological origin, their value for industrial processes in vogue, innovation and technological change. The initial steps, however, were given by a group of scientific experts hired by the Spanish Crown, led by Fausto Elhuyar and Andrés del Rio, discoverers of Wolfram (1783) and Vanadium (1803) (Manuel Velera Candel, 2006). That group of experts deployed, at the Royal School of Mines founded in 1792 in the city of Mexico, knowledge and experience acquired in major institutions in Europe, as discussed below, and made the first models of technological innovation for drainage mines and iron production, as it was happening also in other regions of Europe.

STATE OF THE QUESTION

The years of 1770-1850, accepted in the literature to discuss the Industrial Revolution period, framed the last fifty years of the Viceroyalty of New Spain and the first thirty years of the new Mexican nation-state. In that period of eighty years the nature of work processes was dominated by the factory system. The technological innovation and diffusion, as a symbol of progress and social well-being, placed the *educational factor* and *formation* of qualified *human resources* in the centre of the modernizing changing times. The transformations experienced by the Western society, Europe and America, essentially modified their relationship with the natural environment they inhabited, their economic systems, social structures, political institutions and ideology (Lafuente *et al. (eds.),* 1993, Weinberg, 1998, pp. 41-122).

Still in 1761, Francisco Javier Gamboa had the training of miners as a private matter. But that changed when in 1774, along with two representatives of the mining guild, Juan Lucas Lassaga and Joaquin Velazquez de Leon, recommended the creation of an institution of vocational education which modeled the formation of mining on a scientific basis (Flores Clair, 2000, pp. 23-37, Hausberger, 2009, p. 631).

Francisco Javier Gamboa in their Comments to the ordinances of mine, described in detail the technologies applied in mining, and as for the underground geometry, he listed a number of books written in German and Latin, which were of much benefit in mines. As well, José Antonio de Alzate y Ramírez published several articles on a steam engine to drain mines and on methods for ventilating galleries. "These examples should suffice to show that in America there was great interest in modernizing mining technologies. They also had the initiative to learn the new European science, although it was not as easy to keep updated, this lack of information caused great desperation in Prudencio Pedro Perez (Hausberger, 2009, p. 631).

In that scenario, illustrated *novohispanos* and naturalists and physicians employed by the Crown to carry out their teaching and research at the Royal School of Mines in Mexico City (1792-1823) were aware that the overall and sustained increase in the production was due to the mechanization of the processes. Therefore, they recognized the advantages new equipment, techniques and new products circulating in the Atlantic trade. Joaquin Velazquez de Leon (1725-1786), Juan Lucas de Lassaga (-1786), José de la Borda (1700-1778), Manuel de Aldaco (¿-1770) Francisco Javier Gamboa (1717-1794), José Antonio Alzate (1737-1799), Joseph Garcés y Eguía, Francisco Javier de Sarria, Fausto de Elhuyar (1755-1833), Franz Fischer *(ca* 1757 - *ca* 1814), Friedrich Traugott Sonneschmidt (1763-1824), Luis Fernando Lindner (1763-1805) and Andrés Manuel del Río (1764-

1849), among others were part of the group of naturalist who sought to combine theory with practice, observation of nature with the experimental measurement of natural phenomena with the development of mathematical and chemical models.

That group of illustrated *novohispanos* and foreign naturalists engaged in teaching and applying new knowledge to mining activity, which was the stronghold of the colonial revenue assumed in its teaching and research the principles of physics to substitute the force of the blood - the man and the beast- on the other inanimate in the drilling, mining and mine drainage, which was the biggest obstacle the mining economy faced. Like their English peers, German or French, they also sought in his work of observation, experimentation and measurement of natural phenomena, laws governing nature and matter; for example, the action of water power or steam to streamline the instrument or machine. By experimenting with new force power, they sought to regularize their speed and to make more solid the technological artifacts; they replaced wood joints by metal. That was also happening in Europe.

This phenomenon spurred by the Industrial Revolution triggered the global consumption of minerals (Ashton, 1973; Rosenberg, eds 1979; Cazadero, 1995) and placed in a privileged position the domain of knowledge and technical skills (Pollard, 1991, pp. 9. ff; Michell, 1976; Reséndiz Núñez, 1979). In the American case, it was not about replacing the local European technology, but to innovate according to terrain features, geognosy, mineral chemistry, orientation and thickness of the veins, the local labor organizational culture, property systems, and credit mechanisms and funding to find a balance between cost and benefit. Friedrich Traugott Sonneschmid wrote in 1790: “mining in general, as well as all the machinery used in the mineral extraction and in the benefit deserve to be improved, however it is all much better here in America than people imagine in back in Germany”. Later Sonneschmid wrote a whole book in favor of the amalgamation performed in the New Spain, “to do justice to this outstanding method that European has treated with quite contempt” (Hausberger, 2009, p. 634). Andrés del Río also wrote an extensive analytical work with more than 70 titles on different minerals, the geological environment of origin, their usefulness for “the public good” and chemical-mechanical proposals for industrial processing.[2]

This paper examines one aspect of that transition, namely, circulation, dissemination, adaptation and innovation and scientific and technical support to the Mexican reality, through the work of the mineralogist Andrés Manuel del Río. The life of this man of science takes place just at the time of the Industrial Revolution, and his contributions to science and technology are part of this global phenomenon. The central issue is the relationship that is established between the learning process among individuals,

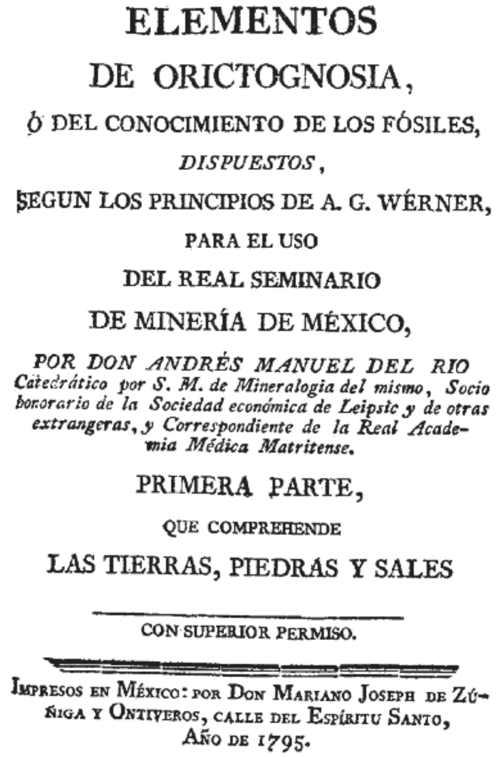
ELEMENTOS
DE ORICTOGNOSIA,
Ó DEL CONOCIMIENTO DE LOS FÓSILES,
DISPUESTOS,
SEGUN LOS PRINCIPIOS DE A. G. WÉRNER,
PARA EL USO
DEL REAL SEMINARIO
DE MINERÍA DE MÉXICO,
POR DON ANDRÉS MANUEL DEL RIO
Catedrático por S. M. de Mineralogia del mismo, Socio honorario de la Sociedad económica de Leipsic y de otras extrangeras, y Correspondiente de la Real Academia Médica Matritense.
PRIMERA PARTE,
QUE COMPREHENDE
LAS TIERRAS, PIEDRAS Y SALES
CON SUPERIOR PERMISO.
Impresos en México: por Don Mariano Joseph de Zúñiga y Ontiveros, calle del Espíritu Santo, Año de 1795.

Figure 1. *Elementos de Orictognosia*, by Andrés Manuel del Río.

inventors or innovators, and technological changes that characterize the changes incurred during that period. At this point it should be noted that Andrés del Rio was able to combine knowledge with reality. Unlike their German and English peers who “taken by a boundless faith in scientific progress” failed in their attempts to translate the European processes and technology models to the American reality (Hausberger, 2009, p 629; Platt, 1999, pp. 37-102), Del Rio promoted technical modernization taking into account the historical, social and cultural contexts and local technological innovation tradition itself.

SCIENTIFIC AND TECHNOLOGICAL LEARNING OF THE INDUSTRIAL REVOLUTION

Since the second half of the eighteenth century, countries like England, Germany, France and Spain with more scientific network established the first higher education institutions and governments financed scientific expeditions to different geographical parts of the world and hired the services of renowned men of science for this purpose (Uribe Salas, 2006, pp. 231-260).

Andrés del Río was one of those men who came to New Spain in the last years of the eighteenth century hired by the Spanish government to form mining officials skilled in the arts of metals in two areas: to promote research on mineral resources; and to promote technological innovations in the royal mines that would ensure the smooth running of the mining operations and finances of the kingdom.

He had previously studied at prestigious European institutions like the *Royal Academy of Mines of Almaden,* Spain (1782-1783), *l'Ecole Royale des Mines,* France (1785-1786), *Collège de France,* France (1786); *Bergakademie Freiberg,* Saxony (1787-1789); Royal *Academy of Mines and Forests,* Hungary (1790); *Laboratory of Arsenal,* France (1793-1794), among others, and since then he remain linked to major international scientific societies were new technological theories and paradigms were discussed (Uribe Salas y Cortes Zavala, 2006, pp. 491-518).[3]

At the Royal School of Mines in Mexico City he was in charge of the class of mineralogy from 1795 to 1847, with some interruptions. As professor of the class of mineralogy, he formed in their classrooms to a significant number of students[4] who contributed to the development and consolidation of the mineralogy and geology of Mexico in the second half of the nineteenth century (Uribe Salas, 2006, pp 231-260; Uribe Salas y Cortes Zavala, 2006, pp 491-518).

At that time he combined his teaching job with his research activities; translations of manuals and treatises on Orictognosia, geognosy, Geometry Groundwater and Geology (B Argallo, 1966, pp. 11-79; Rubinovich Kogan, 1992, pp. 3-70); he also held various official commissions as analysis of fossil material referred from different parts of the country to the Royal School of Mines, in the construction of the first machine to drain water columns mines of Moran (1799 and 1800); in establishing the first industrial foundry in Spanish America, located in the region of Coalcomán (1805-1809); in technical assistance to entrepreneurs from Puebla in ceramic industry in 1830; and exploratory scientific committee of the Istmo of Tehuantepec, which produced the first geological map of the region in 1843 (Del Rio *et al.*, 1843, pp. 2-3; Ramírez, 1891, pp 310-320; Robles, 1937, p 11; Bargallo, 1964, pp. 255-261).

Reader of the great works of thought of his days, he read in Latin, French, German and English, he added to rationalist thought in a clear break with the scholastic, and defended the principle that all the ideas, systems and methods result in a dialogue with the specific concerns of those who present them. A source of wisdom that fueled the spirit of Andrés del Rio should have been the work of Gaspar Melchor de Jovellanos (1744-1811), that can be seen in the principles del Rio adopted in New Spain / Mexico on the roll of the education, the economic means to promote happiness and freedom of the arts (Jovellanos, 1781, 1785, 1790, 1793, 1796-1797, 1797).

For Del Rio there is no copy or passivity, but dialogue in the quest to unlock the mysteries of nature. For him, knowledge of different philosophical, scientific and technological concepts feed the spirit and widened the possibilities of observation of facts, phenomena and physical objects that are still unknown or little known to the international scientific community.

Andrés Del Rio spent all his life immersed in the process of learning science and technology that surrounded the Industrial Revolution. At that time, technological innovation processes were in most cases the result of individual technological learning.

HIS TECHNOLOGICAL CONTRIBUTIONS: COPY OR INNOVATION?

The case of Andrés del Río is paradigmatic considering his contribution with the discovery of erythronium and the chemical composition of other mineral substances unveiled in Mexico. In such discovery, Del Rio invested time and resources; at the same time the observation and experimentation were detonating new and original situations about some aspect of the natural reality unknown in those days. All together, it but would modify and enrich the understanding the society had and which today, for example, is know as the element 23 of the periodic table (Andrés del Rio, 1803, 1804; Amorós, 1959, 1963: pp. 937, 1964, 1985; Puche Riart, 1993).

The other facet of this character is related to technology, or rather, with the ability to promote in the royal mines the technological innovations that would ensure the smooth running of the operation and finances of the kingdom. In that area three elements came together: a) the economic interests of the mine owners; b) Spanish state capacity to generate or use new technical procedures and mechanical devices that would enhance the productivity of the mines, and thus royal incomes; c) the body of knowledge and technique Andrés del Río had, allowed him to design and / or create goods and services that facilitated their adaptation to the environment, meet the essential needs of the mining in the New Spain, the wishes of the Royal General Tribunal of Mining.

At this point it should be noted that even though Andrés del Rio wanted to copy the instructions from books and manuals: for example, its own *memory on a machine to extract of the waters of mines from Shenmitz* (1788) or *Traité sur les mines et les forges de fer du comté de Foix desclasant* from Lapeyrouse (1786) the design and construction of both the water pump constructed in the mine Moran, as well as the establishment of the *Forge of Our Lady of Guadalupe* in the mountains of the Bishopric of Michoacán, were largely the result of his own creativity, expertise and mechanical improvement.

In both cases, Andrés del Río confronted their own knowledge and ideas through observation and experimentation, and subjected to harsh criticism of other inventors who were presented as experts. He did not invent anything according to Michele Lambert's (Lambert, 1995) concept of invention as the creation of new devices, objects, ideas or procedures (which are relatively new and unique) for a human target. Instead, his work can be considered as a technological innovation, since in both cases, he introduced changes to both the design and technical procedures that made the water pumps and forge ovens artifacts to improve and optimize the development of processes, services and products.

In any case, the professional services required to Andrés del Rio had other grounds that the mere teaching of mineralogical science, perhaps more urgent and practical from an economic and productive point of view. The urgency was to get the mining out of the prostration it had fallen, applying knowledge of modern sciences to solving concrete problems for locating production of quicksilver deposits, paramount element in the extraction; mine dewatering, and last but not least, exploration of iron deposits for exploitation with industrial character.

Under the circumstances, there were other experts in the area like Fausto de Elhuyar, Franz Fischer, Friedrich Traugott Sonneschmidt and Andrés del Río; but considering the knowledge, skills and experience, the task was assigned to the latter. Andrés Manuel del Río combined these activities in his life in Mexico, but his work draining the mines of Moran in the mining district of Real del Monte and the establishment of a foundry in Coalcomán represented his skills and expertise in the design, planning and execution of two work of engineering, one hydraulic and the other industrial, the first of its kind in the new continent.

THE MACHINE WATER COLUMN AND THE MORAN MINES

The mines of Real del Monte, along with Guanajuato and Zacatecas, represented the symbol of the wealth of the Viceroyalty of New Spain. But from the mid-eighteenth century mining had entered a period of decline, a result partly of two factors: the deeper extraction of minerals and abundance of water by the effect of runoff, which flooded the galleries and made it impossible the access to the veins. In such circumstances, both the Crown and the vice regal authorities searched for the best men of science to find practical and sustainable solutions. They appealed, then, to the pensioners of the kingdom, which had been sent to France, England, Saxony and Hungary to prepare for new techniques on mines, metallurgical processes and technological innovations.

Apparently it was Andrés del Rio, in his formative stage, who was asked to gather all possible information about the experiments being made in Shemnitz mines in Lower Hungary, with a machine to extract its waters. The result is in the *memory on a machine to extract the waters of mines of Shenmitz* that he sent to Antonio River Valdez on July 25, 1788,[5] in this report he made accurate descriptions of both the characteristics of the machines as its dimensions and material that had to be built, always depending on the conditions and characteristics of the place, to operate successfully. This was perhaps the preamble Del Rio had with the American reality and what took him to accept being commissioned as an expert in the New Spain.

As soon as Andrés Del Rio arrived to Mexico City in 1794, and after teaching the first course in mineralogy in the new continent the following year, he traveled to the mines of Moran to learn about the problems miners were facing to drain the galleries. Del Rio had to make several trips to Pachuca from 1796, but it is possible that his stays were longer between 1799 and 1800, which is the period in which it is built and set the water column machine. This machine, the first of its kind ever built in America, was considered far superior to those that existed in the mines of Hungary (Bargalló, 1955, pp 342-343). Andrés del Río was responsible of the calculation, design, construction and installation with the assistance of Pedro Chaussé, a French craftsman technician, and Nicholas Tubuira.

There is no doubt that Andrés Rio took into account the data he collected in his *report on a machine to extract the waters of Shenmitz mines*, but it was his knowledge and experience gained in Europe which allowed him to develop a mechanical model based on careful observations of the geological structure of the local mines and the principles of physics and mathematics to the construction, size and capacity of the various components of the device. The result was a combination of ideas and knowledge on some new manifestations of the geological structure of the mining area that encouraged plenty of water runoff, and on the other hand, the combination of mechanical components, and gave as a result an artifact seen in the history of technology far superior to the existing at that time in central Europe (Bargalló, 1955, pp. 342-343).

The construction of this machine, “whose cylinder is 26 decimeters in height and 16 in diameter” and its adaptation to the topography of the mine Morán, took four years and it was in operation between 1801 and 1803 at a cost of 40,000 pesos (Brading, 1975, pp. 228-229; Castillo Martos, 2005, p 220). Alejandro de Humboldt knew about it on her journey to New Spain, and expressed appreciation to the expertise of Del Rio as the pump water columns “was superior to those used in Hungary” (Humboldt, 1978).

ESTABLISHMENT OF THE FIRST INDUSTRIAL FOUNDRY IN SPANISH AMERICA

With the development of productive activities and the consolidation of the colonial system in new overseas positions, the economy of the Viceroyalty of New Spain increased consumption and demand for a variety of items and products that were only produced on the mainland or were marketed in its Atlantic possessions. The Crown did not actually prohibit its exploitation in colonized lands but retained the commercial monopoly of iron and steel. For this reason, the bulk of the iron ore consumed in the domestic market novohispano was imported from Spain. These minerals came from the region of Vizcaya, Spain, and were shipped to New Spain in bars, rods and plates; along with them, came large shipments of nails, all kinds of tools for mining and agriculture.

The development of the colonial economy, especially in the last half of the eighteenth century, demanded large amounts of this mineral that the Crown could not always satisfy. During these years the conflicts between Spain and England forced the Crown to suspend shipments, causing a shortage in the market and temporary cessation of production activities that depended on this supply. When this occurred, they used some other known minerals, but they were abandoned as soon as the vessel traffic was reactivated. A document of the time states “it is impossible to work (iron deposits) in peacetime due to cheap iron and Spanish steel and for the lack of fuel” (Florescano and Gil, 1973, p. 168). The German scientist Alexander von Humboldt relates that a few years before his arrival in Mexico as a result of one of many interruptions, “had raised the price of iron from 4 to 43 the *quintal* and steel from 16 to 260 pesos“. In this time, 1794, they had successfully exploited the Tecatitlan mines near Colima. But it stopped working when they first arrived in Veracruz the remittances from the peninsula (Humboldt, 1978, Chapter XI; Othon de Mendizabal, 1946, pp 77-78). Regarding the iron located in southwestern Michoacán, it was exploited until the late colonial period.

As part of the war of 1804-1805 between Spain and England, which cut communications and trade between the metropolis and its overseas colonies, New Spain authorities prepared a strategic plan to replace foreign remittances to domestic production. To this end, they commissioned the Spanish mineralogist Andrés Manuel del Río, studies and the establishment of a foundry in New Spain territory.

The mineralogist del Rio welcomed the new assignment, and “after studying the geological map of the vast territory of New Spain, it was decided that the cheapest mineral must be drawn from the rich mines of Coalcomán (located in the southwest of the then Bishopric of Michoacán), the closest geographic location to the capital of the kingdom, though not the richest iron ore in the country as were those of Nueva Vizcaya (Durango), Antequera (Oaxaca)“ (Sánchez Flores, 1980, p. 252).

In this project both the authorities and the miners themselves, put all their efforts and hopes, as the iron that would be obtained from Coalcomán was thought to supply the domestic market demand. Such circumstances gave international guidelines for the introduction and application of modern technology once ignored for the exploitation of iron. Andrés Manuel del Río not only applied his vast knowledge of chemistry, physics, geology and mineralogy, for this project, but along with a group of students of the College of Mining, technical and practical miners, designed and built the facilities of the first ironworks in the Spanish America, which opened for Latin American science and technology new development prospects. In the forge of Our Lady of Guadalupe, as it was named this production unit, Andrés Manuel del Río with the help of his disciples, José Mariano Oteiza, Rafael Dávila, José M. Herrera and Rafael Cardoso, built a hearth of large proportions and a blast furnace, the latter according to designs by The Peyrousse commented in his book. The facilities of these “French ovens” as Del Rio used to call them, included “vaults of 30 feet high, which could only hold in the walls of a factory rather tall” (Ramirez, 1875, pp. 251-253). According to the above, it is likely that the blast furnace designed by Del Rio in the forge of Coalcomán, had been similar to those in the “Forge of San Mauricio” installed in New France, and it coincided with the height of 30 feet reported for both cases. This similarity is not surprising given the common origin of the design, which also explains the name “French” given to their oven (Habashi, 1975, pp. 24-27).

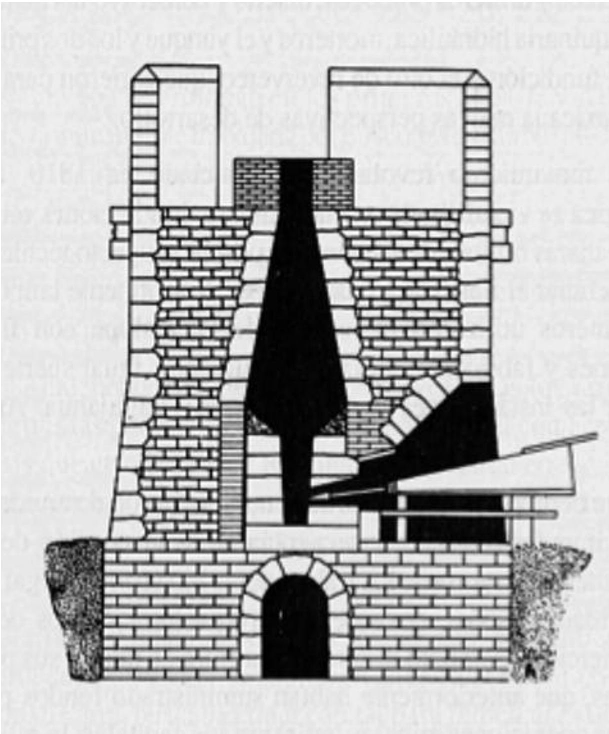

Figure 2. Design of the first blast furnace built by Andrés del Rio in Coalcoman, Intendencia de Michoacan, New Spain, 1805-1809.

Andrés Manuel del Rio adopted iron production scheme developed in England around 1760, which was originated and motivated by the substitution of charcoal used previously as blast furnace fuel for coking coal, which had the disadvantage of introducing impurities in molten iron, mainly phosphorus and sulfur, which made it brittle and fragile. This production scheme was to obtain a better quality iron as a result of consolidation in hearth furnaces to improve the obtained impure iron in the blast furnace (Derry and Williams, 1977, p. 692). From the first essays documented in the forge of Coalcomán during the year 1807, it is possible to suggest that Del Rio used the hearth to "puddling" the obtained impure molten iron in the blast furnace. In the Middle Ages, and until the late nineteenth century, many European countries used as steel method the Catalan *farga*. Iron and low carbon steel was obtained using charcoal and iron ore. This system was already in place in the fifteenth century, and it could reach up to 1200 ° C. this procedure was replaced by the one used in the blast furnace. Initially charcoal was used for obtaining of iron as a heat source and reducing agent. In the eighteenth century, in England, began to dwindle and become more expensive the charcoal, and they started to use coke, a fossil fuel used as an alternative. It was first used by Abraham Darby, in the early eighteenth century, who built a blast furnace in Coalbrookdale. The blast furnace was developed over the years. In 1784 Henry Cort implemented new and improved production techniques, Andrés Rio learn about these techniques in England. Henry Cort perfected the puddling process in 1784 to convert pig iron into wrought iron in a reverberatory furnace. In 1790 there were in England 81 coke ovens compared to 25 who used charcoal.

Therefore, the process of "puddling" of iron, invented by Englishman Henry Cort in 1784,[6] Del Rio used it in Coalcomán, This process consisted in "removing, tearing, breaking and separating in the oven" (Derry and Williams, 1977, Vol I. p. 692 and 696) pieces of refined iron and by hammering these pieces received blooms or lumps shapes. This process made iron more ductile and malleable because of the strong decarburization it suffered, since in the hearth oven there was no risk for impurities from coal, and the coal itself, to be transmitted to the metal, because only the hot gases passed from the hearth to the top of the oven, where the heat was reflected by the metal dome on refine (Derry and Williams, 1977, Vol 2, pp. 690-693; Gayler, et al. 1965).[7]

Andrés Manuel del Río also built a canal 3,300 yards (2.765 meters) long to use the waters of the Astala River. This water moved the mills and the forges. These waters were also indispensable for operating the tubes used to inflate the furnaces (Sánchez Flores, 1980, p 252; Derry and Williams, 1977, Vol.1, p. 211; Ramirez, 1890, p. 229).[8] After the carpentry, the water tanks for the machines ready, shots and tunnels for ore extraction open,[9] and able to function the tubes and furnaces, the forge began to melt on April 29, 1807, with Andrés del Rio in charge (Creir *et al.*, 1969, pp. 1-40).

In the year 1807, and corrected the flaws noted in the first experiments, it began to produce iron blooms or lumps with an average weight of 104 kilograms loads obtained from 368 kilograms of ore at an approximately time 6 of hours. "The quality of the iron was outstanding; the first consignment arrived in Guanajuato on August 18, 1808, Mr. Casimiro Chovell,[10] the Valencia manager, took four pieces to test them, the results he got pleased him so much that he bought all the existing amount; he continued receiving all the following remittances" (Ramirez, 1891, p. 231).

> The success with which it was established and guided the metallurgical treatment, coupled with the good kind of iron, gave the expected result; and the same Mr. Del Rio, paying attention to the most delicate parts, all the carefully performed processes resulted in better and longer lasting iron than those of Viscaya (Ramírez, 1891, p. 231).

With the place working, on April 12, 1809, Andrés del Rio requested authorization from the Royal Tribunal of Mines to leave the place, presenting the statement of expenditure incurred from 25 November 1805 until 25 April 1809, amounting to 98,509 pesos and 2 reales and with a production of 17,434 kilograms of iron (Quiroz, 1817, pp. 252-254; Sánchez Díaz, 1979, p. 79).

When Andrés del Río left the forge of Guadalupe to conclude his studies at the Royal School of Mines, the operations were under the direction of José Mariano de Oteiza, one of his most prized students at that institution. Del Rio aware of the significance of the forge of Guadalupe in the advances of the science and technology of the new continent, proudly said at the closing ceremony in Coalcomán on May 18, 1810, without knowing or even imagining the events that lay ahead…

> …while in danger of disappearing from Spain its ancient ironworks under the emergence of modern vandals, here we work quietly in metallurgical experiments under the generous auspices of the Tribunal of Mines in a corner of America, which is on the day, thanks to providence, asylum and peaceful home in the natural sciences, as once the cloisters of the monks were of abstract science and humanities (Del Rio, 1810).

As later was referred by Santiago Ramirez, it would have progressed further if it had not been destroyed by the disruption caused by the revolution of independence, which ended with it in October 1811 (Ramírez, 1891, pp. 210-211).

The forge of Guadalupe was considered by Lucas Alamán, pupil of Del Rio, "not only as a branch of industry, but as a necessary element for everyone else, for it is what produces the machines we all use" (Alamán, 1945, pp. 58-59), this forge emerged driven by international factors (war between Spain and England), and succumbed this time due to the revolutionary independence movement. The war that began in 1810 forced us to leave the company. Insurgents and royalist forces fought for the control of the forge for military uses. The first used it to melt the guns, ammunitions and war material until complete destruction by royalist forces "losing the very considerable expense made to create it" (Alamán, 1946, pp. 377-378; Sanchez Diaz, 1979, pp. 79-80).

Years later, with Andrés Manuel del Río still alive, another attempt was made to revive the forge of Coalcomán, with few results. The iron deposits were still attractive for some businessmen and even for thegovernment. In 1827 Pedro Gutiérrez de Salcedo, in partnership with Mariscal de Castilla, Count of the Valley of Orizaba, planned the rehabilitation of the old mines and the introduction of technology. For Gutiérrez de Salcedo "anywhere else on the northern continent has, like this, as many elements to be so great; and the momentum that is about to occur in the exploitation and processing of its ferruginous metals, will increase the population, and will offer a great deal of jobs for everyone..." (Gutiérrez de Salcedo, 1905, p. 8). And indeed, the activities undertaken to revive the forge of Guadalupe attracted groups of workers from neighboring counties, the population increased and the commercial activity was encouraged. Between 1827 and 1830, according to the data we have, the population of the town reached 1,000 residents and 500 the adjoining villages. The steel mill established by Del Rio was in reconstruction when the revolution of 1830 broke out,[11] one of many political movements that swept the geography of Mexico during the first half of the nineteenth century, sowing distrust and anxiety among entrepreneurs and the public. Here, as in other Mexican mineral exploitation was restricted only to hustlers or rescuers (Romero, 1993, pp. 45-48).

This case is significant for the skills showed in its construction, closer to the English model than the Spanish (Catalan furnaces) or the French model. It is very interesting to know that Andrés del Río refers to the work *Traité sur les mines et les forges de fer du comté de Foix desclasant* (1786), written by the French lawyer and naturalist Philip Picot de Lapeyrouse, since Picot was not an expert. However, Del Rio reports

> I thought myself fortunate to have on hand this modern, elegant and masterful work of Lapeyrouse, which according to its author is the result of ten years of observations, not in one but in several forges of its kind, I thought I was lucky, I say, and thinking that having to ford a raging river, suddenly is a newly built bridge, which seems to gather the strength to beauty. And as it is repeated several times in this work that following its rules and precepts it is almost a foolproof way of succeeding, the natural consequence was that I should stick to the letter and follow the footsteps of my mentor. But the instruction I have usually follow, and in some ways it has helped me a lot, is that the decisive tone is of no use in the subjects awaiting further progress each day of observation, and what more can be said: repeat my experiments, and if they do not work correctly, change them according to the principles of a healthy theory: that is, in other words that the books you plan to write merely for practical, are the least useful for practice (Ramirez 1891, p. 31).

Like many inventors and technological innovators of the Industrial Revolution, Andrés del Rio had to solve alone, but with "a healthy theory", the adequate physical, mathematical and chemical principles to determine the dimensions of the furnaces, heat resistance of materials and metallurgical processes taking into account the nature of the ore, its composition and the melting point in order to receive the purest and durable iron.

> This has happened to me in the most important part of the casting, the dimensions of the furnaces, which Lapeyrouse assumed as essential, that an inch of difference produces the most disastrous results, and therefore transfers with thick plates of iron garrison to figure that does not vary in the cast. And now to build my oven with ladder in hand, I found so much ambiguity, so much confusion and even contradictions, which even today I do not know, what are the decanted measures of the author: something very strange in a man who is usually quite clear and others rather confusing, so I do not know to what attribute its conciseness and darkness at this point. One of two things: either he never measured the ovens by itself, but contented with measures that were given to him, some at one time and some at another, because they do not make any sense, or he decided not to tell the most essential part, and then he could have done all the work, and having buried forever. It is not my intention to demerit his work, I stick to it first, as to what this speech is directed is to ask for lights to all intelligent, to give the greatest perfection to the facilities in Coalcomán (Del Rio, 1810, p 1).

Just accompanied by their students and some other skilled craftsman in some useful area for the intended purpose, but as we have said, almost alone in the vast mountain Sierra Madre Occidental located in the Intendencia of Valladolid, these passages of his work demonstrate the interrelationship between the process of scientific and technological learning he had acquired in the years prior to his arrival in the New Spain and the processes of technological innovation that characterized the changes in that period. At that time, as we have noted above, technological innovation processes were in most cases the result of individual technological learning. But it is visible that Del Rio was immersed in the scenario of technological change brought about by the Industrial Revolution.

For Manuel Ruiz González "innovation comprises, therefore, all the scientific, thecnical and commercial stages, necessary for the successful development and marketing of new products or with improved characteristics, the use of new and improved processes and equipment, or the introduction of a new service" (Ruiz González and Mandado Pérez, 1989, p. 14). In his role as a technologist, Del Rio transformed his ideas and knowledge in processes, services and enhanced products in a changing and involving era, and since then, the “demand” and the “science”.

CONCLUSIONS

In the case of the water pump and the establishment of the foundry is not about transfer or loan of technology, it rather falls in the process of adoption and adaptation of models with clear elements of innovation, which was also being tested in other latitudes with varying effectiveness. Del Rio managed to materialize for the first time a technology to dewater the mine and produce iron in New Spain. This process was made in the field of innovation, as they were, of course, new ways to reach certain goals. It is also possible to talk about innovation in the sense that the artifacts produced as technical procedures, implemented new technology that became commercially exploited, even if was only for a short period of time in the case of New Spain.

We cannot assess its impact on productivity growth, because as we all known, environmental factors, economic and military order that hampered its functioning and operation were present, and unfortunately these factors ruined the experience gained. I can conclude, however, that what Andrés del Río did is the basis of technological change that it was only possible decades later through technology transfer, and not by the work of invention and innovation that was undertaken. “The hegemony of Western science was not finally established only with taxation and intolerance, but also due to the materials results it got, from the steam engine to cyanidation or the atomic bomb” (Hausberger, 2009, p. 642). In words of Hausberger, Andrés del Rio had a leading role in the advancement of science and technological innovation, as large or as small as an individual can have them.

In any case, the opening of the Royal School of Mines in 1792 and the hiring of experts on the requirements of the Industrial Revolution shows the interest of the Spanish State by promoting policies in the fields of knowledge and technology related to productivity and economic growth based on the ability, both to generate and to use new technologies. So, for something to be innovative, it was necessary to be useful for a group, institution or government, and most importantly, it should completely cover the needs and not just to be a partial solution.

Andrés del Río was against, with his scientific practices that developed in the “New World”, to the increasingly widespread belief that there was a hegemonic science across the Atlantic. In his practice in New Spain (1795-1821) and Mexico (1821-1849), he welcomed the internationalization of science, which included his own achievements as part of the universal progress. In New Spain-Mexico there was also a conviction for science, despite the social conditions were different from those of other countries that had achieved greater scientific tissue. Del Rio managed to prove that knowledge and technological innovation, originality and effectiveness were the result of a historical setting and cultural contexts that determined their progress.

NOTES

[1] This work was supported by CONACYT / Mexico for Overseas Sabbatical 2014, and it is part of a larger research related to the scientific project headed by Dr. Miguel Angel Puig-Samper at the Institute of History of CCHS / CSIC: *Ciencia y espectáculo de la Naturaleza. Viajes científicos y museos de Historia Natural*. Referencia: HAR2013-48065-C2-2-P. Madrid, España, 2015-2016.

[2] Currently I am preparing the book: *Andrés del Río: su formación científica en Europa y su desempeño en America*. It provides a detailed study of their intellectual and scientific training; his stay at some of the major educational institutions in Spain, Saxony, Hungary, France, England and New Spain / Mexico; the circulation of knowledge and networks in which he was involved on both sides of the Atlantic. Also, his contributions to chemistry, geology, paleontology and mechanical arts.

[3] In this international “scientific community” still small, stands out the names of some of his teachers and colleagues, Christophe Störr, Jean D’Arcet, Abraham Gottlob Werner, Anton von Rupprecht, Leopold von Buch; Laurent Lavoisier; Just Haüy, Dieudonné Dolomieu (Diodone Dolomeo), Alejandro de Humboldt, Saussure Benedict and Luis Lindner.

[4] Casimiro Chovell, Francisco Álvarez, José Joaquín de Zárate, Vicente Herrera, José Antilla, Manuel Cotero, Manuel Cueto, Félix Rodríguez, Vicente Valencia, José Oteiza, Sixtos Cardona, Rafael Cardoso, Juan Arezorena, Manuel Ruiz de Tejada, José Bustamante, Ignacio Alcocer, Sebastian Segura, Joaquín Velásquez de León, Lucas Alamán, Blas Barcárcel, Antonio del Castillo, Francisco Díaz Covarrubias, Manuel Riveras Cambas, Manuel Fernández Leal, among others.

[5] Archivo General de Indias (AGI), Maps and Plans. Mines, 48, and indifferent, 1795 D EL Rio, A. (1788), Report on a machine with which the waters are extracted Shenmitz mines in the lower Hungary, sent to Antonio Valdez on July 25.

[6] The Henry Cort, 1740-1800, England. Inventor of the puddling process, also known as the reverberatory furnace. He is credited with having perfected the rolling mill with grooved rolls. The “puddling furnace” removes a mass of iron furnace using a stirring bar. The extracted metal ball is then processed in a shingle for shingling a hammer, after which it rolls.

[7] The fact is that the production of cast-in that was used with great success-the new process was much less important now that the conversion of pig iron into wrought iron, whose malleability and tensile strength made him the king of metals votes until the discovery of cheap steel.

[8] The tube or trompe, Italian invention was one of the most used for air inyected performance without manual or animal power methods. It was in use in the southern U.S. until the late nineteenth century, French horn uses the compressive strength of a column of water that falls within a closed space, pushing air into a chamber and thence into the oven.

[9] The molten mineral River in the forge of Coalcomán was known as “brown iron”, which corresponds to the currently called Limonite hematite hydrated chemical formula FeOOH.

[10] Casimiro Chovell had been a student of Andres del Rio in the Royal Seminar of Mines in Mexico.

[11] *Empire Journal*, volume I, no. II, Mexico, January 14, 1865, p. 44.

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