From Wood to Steel. The Transformation of the Mining Machinery in Mexico

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Abstract. This chapter compares the principal machinery used in the Mexican mines during two different periods: the Spanish colonial time, from the 16th century to the beginning of the 19th century, and the initiation of the Industrial Revolution. Mining and metallurgical processes drastically changed from wood and animal power to steel and steam engines in a few years. The changes were more than only material and power; they implied new organizations, technical development, and skills. During the colonial period, machines and metallurgical processes were locally developed, and the working organization depended on intense labor activities and animal power. During the steel period, influenced by the Industrial Revolution, production significantly increased due to better machines, the use of explosives, and improvements in transportation systems. This chapter contributes to disseminating the evolution of technology, comparing the technological transformation of machines and mechanisms and their relation to other factors such as commerce and social development.

Keywords: Mining machines · Industrial Revolution · Animal power

1 Introduction

In the first quarter of the 19th century, Mexico, like most Latin American countries, became independent from Spain. The independence coincided with the beginning of the Industrial Revolution, which modified every aspect of society. The impact of the Industrial Revolution on the Mexican mining machinery, not only technologically but socially and economically, remains up today. The transformation of mining machinery in Mexico from the 18th century to the 19th century marked a significant shift in the technology and methods used for mineral extraction. Since mining played a crucial role in the economic development of Mexico during this period, particularly in regions rich in silver, gold, and other valuable minerals, this transformation marked the production structure and companies´ organization. This paper describes the technological change and how traditional wooden machines were substituted by steel-made equipment.

This chapter belongs to a series of papers the author has published related to antique machines used in Mexico during the colonial period [1–3]. Most of these machines were developed locally and were critical factors in the competitive position of silver production during that period.

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1.1 General Overview of the Historical Transformation

This paper is related to the silver production in Mexico during the Spanish colony and its transition to become an independent country. One of the main activities was mining, with a remarkable production of gold and silver. The Spanish King imposed royal ownership over land and subsoil, and upon this rule, he granted individuals and indigenous communities the right to exploit, taxing the production. Thus, the silver production was entirely under the control of private Haciendas. Most of the silver production was sent to Europe in exchange for manufactured goods. At the beginning of the 17th century, in Mexico, there were about 370 silver mines; during three centuries, these mines exported around 56 144 kg, whereas in modern times, this production can be reached in 15 years. The significant restriction was the production speed of the ancient machinery, the dependency on extensive labor, and the need for explosives to extract the minerals from the soil [4–6].

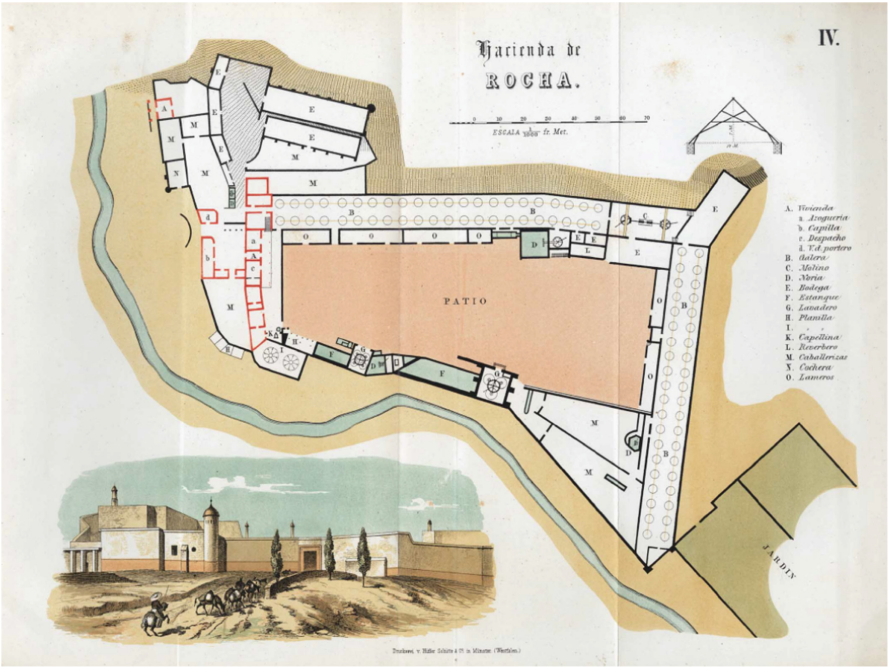

Fig. 1. Layout of the "Hacienda de Beneficio" [7]

During the colonial period, Spaniards had limited control over American possessions. Their sea fleet became obsolete compared to the new ship designs built in Holland, France, and England. Commerce at ports was controlled by local groups that distributed the imported goods inland. These groups were eager to increase their trade with the US and England, thus supporting the independence wars in most Spanish territories.

After the independence, the new Government allowed foreign investors to control local mining. Thus, the new companies installed steam engines and started using

explosives, hammer mills, powered cranks, and rail carts, triplicating the silver production. This production organization set the technology-dependent economy that has characterized Latin America.

Mining machinery in Mexico was transformed from the 18th to the 19th century, characterized by the adoption of more advanced technology, the introduction of steam power, and improvements in transportation and safety measures. These changes contributed to the growth of Mexico's mining industry and its role in the country's economic development [8].

1.2 Silver Process Between the 16th and 19th Centuries

From the 16th century until the industrial revolution, the silver production in Mexico had a unique process [9, 10]. The silver production was based on Bartolomé de Medina's invention (1557). The process was known in Europe but wasn't used there due to the type of minerals. The central part of the process consisted of the amalgam of mercury and silver ore. The amalgam was produced in an open space known as "patio de beneficio" (Fig. 1). Afterwards, the silver was separated by melting the mercury. The ore was milled with hammer mills [3] and then ground with a "tahona" or "arrastre" [2]. Table 1 describes the process.

Table 1. Silver extraction process [3]

Stage	*Description*
Extraction	Silver ore was extracted from the ground with hand tools, carried to the surface with wood carts- sometimes powered by mules- and lifted with wood cranes and winches. From the mines' bottoms, water was lifted with winches and buckets
Grind	The grinding process had two stages: breaking the ore stones into small pieces with a hammer mill and grinding the ore with millstones and water. The output of this stage is a sludge formed with silver ore
Mixture	The sludge was deposited on a large backyard ("patio de beneficio") for producing an amalgam mixing the sludge with brine and mercury. The mixture was padded to ensure a good blend
Wash	Once the amalgam was formed, the mixture was washed with water. The washing process was done in mechanized washer tanks. The objective of this stage was to eliminate the salt and any remaining dust
Filter	The amalgam was filtered in leather bags that separate the water from the amalgam
Fusion	The mercury was eliminated by heating the amalgam. The mercury becomes liquid and flows at a specific temperature, leaving the silver
Foundry	Finally, the silver was melted in a ceramic foundry and cast as ingots

The following section describes the leading equipment used before the Industrial Revolution.

2 The Wooden Period

Machinery during the colonial period (16th to beginning of 19th centuries) was simple, but efficient. Only in some mines they were powered by water mills, but in general they were powered by mules (blood engines). Following the process described in Table 1, the principal machines were:

1. Hand Tools: Miners primarily used hand tools such as pickaxes, shovels, and hammers to extract ore from underground mines. The rocks were transported to the ground by wooden carts pushed by hand.
2. Mule and Horse-Drawn Carts: At ground level, the ore was transported to the Hacienda by mule or horse-drawn carts. The amount of mineral moved was limited by the animal power.
3. Washing: The ore was washed by hand, and some Haciendas had washing machines powered by mules. These machines were unique since they harnessed mules to power the washing operation. Unfortunately, there is scattered information about this equipment, and the author has yet to be able to study it in depth. This process allowed miners to separate heavier minerals from lighter waste materials. Another washing method is the sluice box, a long, narrow channel with riffles to trap minerals while water runs over the ore to wash it. Figure 2 shows a sketch of a washing machine power by mules
4. Hand-Powered Crank or Windlass: In some cases, hand-cranked or windlass devices were used to lift buckets of mineral-bearing material out of mines or shafts. These devices were often simple and relied on human or animal power. The most common type of mule-powered washing machine was the "mule-powered arrastre." An arrastre was a circular or oval pit typically made of stone or wood with a central pivot, where a horizontal wooden axle was fixed. The axle was connected to a vertical post or shaft that extended above the pit. A mule or other draft animal was harnessed to this shaft, and the animal would walk in a circular path, turning the axle and thus rotating a large stone or wooden wheel.
5. Crushing and Grinding: Similarly to the washing "arrastre," the "Tahona" was a particular grinding machine developed in Mexico [2]. The rotating wheel in the "arrastre" was often equipped with heavy stone or metal components used for crushing and grinding ore-bearing rocks. Ore was fed into the arrastre, and as the mules walked in a circle, the rotating wheel would crush and grind the ore into finer particles. Mule-powered "arrastres" are historically significant as they represent a transitional technology in developing mining and ore processing machinery. They were used in the early stages of mining in areas where more advanced technologies were yet to be available. Figure 3 shows a representation of a grinding mill
6. Stamp Mills: Stamp mills were used to crush ore-bearing rock into smaller pieces. They consisted of heavy stamps lifted and dropped by a cam mechanism [3]. Water was often used to wash and separate the finer mineral particles from the crushed ore.
7. Manual Sorting: Miners and laborers would manually sort through the mined material to pick out valuable minerals from waste rock. This method was labor-intensive and relied on experienced workers' keen eyes.

8. Amalgamation: Amalgamation was a standard method for extracting precious metals like gold and silver. Mercury was used to form an amalgam with the precious metal, which was then separated from the waste material through various techniques, including washing.

Fig. 2. Layout of the washing machine [11]

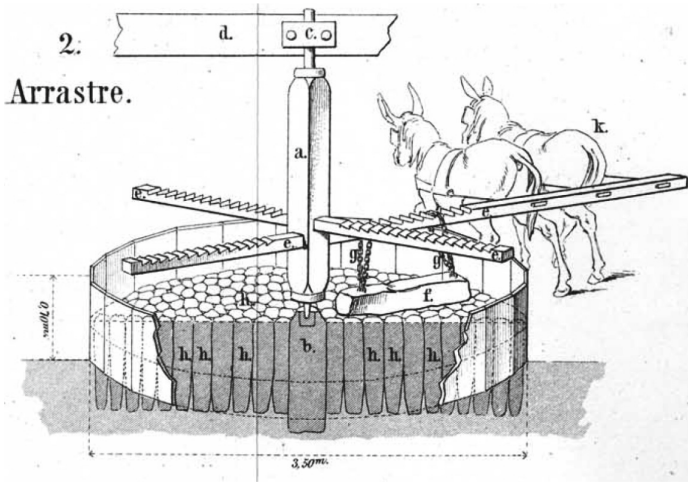

Fig. 3. Sketch of the grinding mill with technical data [11]

The support structures inside the mines were made of wood with timber to shore up tunnels and prevent the caves from collapsing. Ventilation was a big challenge. They generally used natural airflow, and some mines had hand-operated bellows. The hoists were manually operated or powered by mules, all built with wooden pulleys and cables that lifted buckets or containers from inside the tunnels. To keep the mines dry, miners used primitive pumps and buckets to extract the water.

Outside the mine, ground transportation was limited by the power capacity of the mules. Figure 5 shows a sketch of a lifting device that was commonly used in that period. Figure 6 shows the construction of the silver foundries in their current condition (Fig. 4).

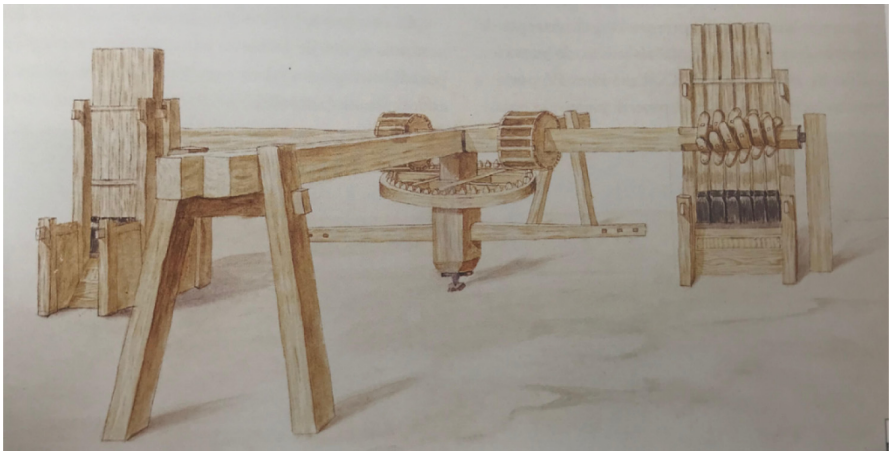

Fig. 4. Schematic lithography of a hammer mill [7]

During this period, mining technology was limited by the available mechanical power and the understanding of engineering principles. The processes were labor-intensive, and the scale of mining operations was relatively small compared to what would come with later technological advancements during the Industrial Revolution.

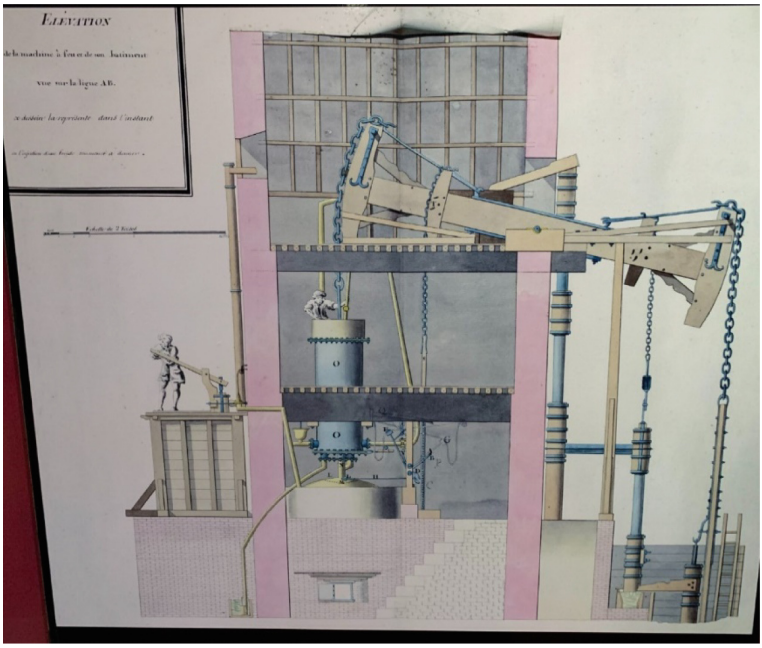

Fig. 5. Layout of an elevation system. Picture taken by the author at "Museo de los Metales https//sic.gob.mx/ficha.php?table = museo&table_id = 1156"

Fig. 6. Silver furnace, colonial period (https://editorialrestauro.com.mx/los-hornos-en-el-beneficio-de-los-metales-en-la-nueva-espana-siglo-xvi-xviii/)

As mining technology advanced, water-powered and steam-powered machinery gradually replaced mule-powered "arrastres" and other manual or animal-powered methods, making mineral processing more efficient and productive.

3 The Steel Period

It's important to note that mining technology evolved over the 19th century, with advancements such as the introduction of steam power and more sophisticated machinery [9, 10]. These improvements increased efficiency and productivity in Mexican silver mines. The foreign investment brought specific equipment that varied depending on the size and type of the mine, as well as technological advancements over time. Here is an overview of some standard equipment used in Mexican silver mines during the 19th century:

1. Steam Power: One of the most significant transformations in mining machinery during the 19th century was the introduction of steam power. Steam engines were used to power various equipment, including pumps, crushers, and hoists. This innovation significantly increased the efficiency and depth of mining operations, allowing miners to access deeper ore deposits. (Figs. 7 and 8)
2. Improved Ore Processing: Advancements in metallurgy and engineering led to the development of more efficient ore processing methods. Stamp mills, which used heavy metal stamps to crush ore, became widely used, replacing earlier, less efficient crushing methods.
3. Rail Transportation: The 19th century saw the introduction of railways in mining areas, significantly improving ore and minerals transportation. Railways facilitated the movement of large quantities of ore from mines to processing plants and ports, enabling the mining industry to expand.

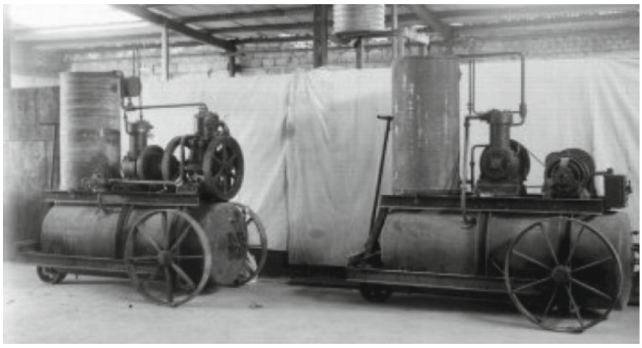

Fig. 7. Layout of the washing machine (http://mediateca.inah.gob.mx/repositorio/islandora/object/fotografia%3A104492)

Fig. 8. Lifting pulley with steel cables (http://mediateca.inah.gob.mx/repositorio/islandora/object/fotografia%3A485386)

4. Safety and Ventilation: With deeper mining operations, safety and ventilation became essential to improve within the mines. Techniques for providing adequate ventilation in mines and ensuring the safety of miners were enhanced during this period. As mines went deeper into the earth, ventilation became a critical concern. Ventilation systems, often using manual fans or animals, circulated air within the mines.
5. Candles and Oil Lamps: Lighting in the mines was crucial, and initially, candles were used. Later in the century, oil lamps became more common.
6. Hand Drills: Miners used hand drills to create holes in the rock for placing explosives. These drills were manually operated and required significant physical effort.
7. Explosives: Dynamite and other explosives became more widely used to break up large volumes of rock, increasing the efficiency of ore extraction.

Fig. 9. Steel carts and tracks for moving minerals outside the mine (https://cienciauanl.uanl.mx/?p=4176)

Fig. 10. Foundry oven and moving machines http://mediateca.inah.gob.mx/repositorio/islandora/object/fotografia%3A485418

8. Mine Carts and Rail Systems: Ore, rock, and other materials were transported within the mines using mine carts on rail systems. This method made it easier to move large quantities of material.
9. Water Pumps: Mines often encounter water seepage or flooding. Initially operated manually and later by steam engines, water pumps were used to drain water from the mines.

10. Stamp Mills: These mills had a similar operation as those in the wooden period but were built with steel and powered by steam engines. They had the same lifting and dropping principle for breaking the ore.
11. Horse- and Mule-Drawn Wagons: Outside the mines, ore transportation and other materials relied on horse- and mule-drawn wagons. (Fig. 9)
12. Blacksmith Shops: Mines had blacksmith shops to repair and maintain tools, equipment, and machinery. No records of similar facilities exist for the previous period.
13. Assaying Equipment: With the evolution of science and engineering, mines started having laboratories to determine the quality of silver and other metals in the ore.

The metallurgy knowledge and the improvement on process equipment made possible the construction of sophisticated foundries that incremented the productivity (Fig. 10).

The Industrial Revolution had a determinant impact on mining production. It transformed every process and modified the machinery. By the end of the 19th century, the introduction of the electric motor made another significant transformation. Electric motors substituted steam engines, and mines were the first factories in Mexico to have their power plants. According to Robles and Foladori [8], silver production in the XVI century was around 2,000 tons/year (the equivalent to modern measurements); by the XVII century, it increased to 4,000 tons/year. Mainly because new mining areas were found and new mines started operations. The impact of the new machinery is evident in silver production; at the middle of the XIX century, silver production had increased to 8,000 tons/year, and the production almost doubled in 50 years. The production increment had a minimal impact on economic development during the XIX century, but this topic is outside the scope of this paper.

4 Conclusions

Analyzing antique machines and processes requires gathering old information that must be interpreted using current engineering methods. It is clear how the Industrial Revolution modified production processes and social organization and determined the need for engineering management, standardization, and the development of engineering documents. Although this chapter includes only a sample of the information recorded during the Spanish colonial period, it is well known that the engineering drawings and technical data started during the Industrial Revolution.

This chapter describes the sudden changes after Latin America became independent from Spain. In particular, the evolution of the mining machinery was significant. Before independence, namely the wooden period, machines were constructed with wood and stones, and they were powered by mules (commonly known as blood engine), which had a limited power capacity in comparison with the steam engine. The introduction of steel pulleys, cables, rails, carts, and many other tools significantly increased the productivity of mines. Unfortunately, the introduction of foreign machinery limited the development of local technology and defined an economic model that persists today.

This chapter contributes to disseminating the evolution of technology, comparing the technological transformation of machines and mechanisms and their relation to other factors such as commerce and social development.

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