# *The Catalan Process*

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# THE CATALAN PROCESS

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## Introduction

In Catalonia over a long period of time, between the xth century and 1878, some installations were developed, which at first were called «factories» and «fargues», since they manufactured iron and steel of low carbon content of excellent quality. Because of their singular quality, the fame of this metal made in Catalonia spread to many countries. «Fargues» were started in Corsica, the Low Countries, Germany, Eastern India, Madagascar, Finland and along the rivers Orinoco, Mississipi and others. The extractive process used in these «fargues» has passed into history as the «Catalan Farga Process» or just «Farga Catalana». With this technology, raw material was obtained to supply the transformation industries, such as the manufacturing of tool, nails, weapons, grills, etc., which in addition to supplying the national marked, were exported.

Besides the steel obtained from meteorites and native iron, found as metallic nodules in basaltic stones in Greenland and Israel, the ancient civilizations, which had no means of reaching the fusion temperature of iron (1535°C), practiced direct processes to obtain iron, similar to those used by certain tribes in Central Africa. Those tribes still at present, fill holes existing on the ground with iron ore and coal, and encourage combustion by blowing air either by mouth or with bellows make of animal skins. Thus without melting the iron, it is possible to reduce the mineral and obtain a porous and impure metallic mass, which is purified on forging by mechanical squeezing. With a process very likely similar the famous column at Dehli, which weights 6.4 metric tons, was built about 300 B.C.

## Description

The process followed by the «Farga Catalana» consisted in feeding iron minerals (oxides) sufficiently triturated with crushed charcoal in a furnace to which air was blown under pressure by means of a tuyere ending less than 20 cms. above the furnace floor. By the combustion of the charcoal in air, temperatures of some 1200°C could be obtained, sufficient to convert the mineral into a pasty mass consisting of iron nodules and slag remains. This mass was compacted and purified by forging with drop hammers.

It is somewhat difficult to give an exact description of the elements which make up the «Farga Catalana» as a whole, since each installation depended on circumstances, such as location, economic means of the owner, and the creativity of the planners. But in all the «Farga» there was a furnace with its water nozle («trompa d'aigua») and two drop hammers («malls»).

### Furnace

The furnace of the «Farga» was the most important element of this technology. It consisted of a cavity in the shape of a truncated pyramid, the dimensions of the larger base being about 60x50 cms., while the height was some 80 cms. In the industrial bay, the furnace was placed next to a main wall, called «*piec del foc*». All the walls of the furnace presented flat surfaces, except the Windwall opening («*l'ore-contravent*») which to facilitate the extraction of the reduced product, had a convex surface and was partially covered with steel plates. The wall of the furnace next to the «*piec del foc*» and opposite to «*l'ore*» was called «*les porgues*» and contained the tuyere which injected air into the furnace. In a side wall was the «*lleteirol*», a hole for removal of the liquid slag. The front of the lleteirol was the «*cava*» (cellar), a stone wall, without surfacing and slightly inclined.

The characteristics which differentiated this from other con-

temporary iron-making processes was the system used to inject air into the furnace – the water nozzle (Figure 1). This made use of what is now known as the Venturi effect. To accomplish this, water from the river was passed into a reservoir, from which it fell through a vertical tube, which in its upper part had a reduced cross section and holes, named «*espiralls*». The decreased pressure in the reduced cross section resulted in the suction of atmospheric air through the «*espiralls*» into a wind box at the end of the tube («*la caixa de vents*») from which it was injected into the furnace through the tuyere.

The great secret in the construction of the furnace of the Farga Catalana was the inclination of the tuyere with respect to the wall of the furnace, and in the distance between the tuyere and the bottom of the furnace. The incidence angle of the tuyere was between 35° and 45° and the distance from the bottom of the furnace was between 10 cms. and 30 cms.

## Forge

The drop hammer was the element of the «Farga Catalana» used to hot deform (forge) and consisted of the hammer («*mall*») the anvil and the woodwork. The hammer was made up of a mass of steel weighing some 500 kg, at the end of a large shank made from a tree trunk, generally oak, 4 m long (Figure 2).

A water wheel rotated a shaft («*calaibre*»), at the end of which was a steel crown («*bota*») with four lugs («*palmes*»). These lugs depressed one end of the shank, raising the hammer at the other end; further rotation of the calaibre allowed the hammer to fall.

The anvil was made up of the «*pedra*», the «*dema*» and the «*demet*». The «*pedra*» was a large stone, almost completely buried in the ground, very shock resistant, on the upper part of which a rectangular hollow had been made. Into this was inserted a rectangular steel block («*demet*») held by means of steel wedges («*dema*»).

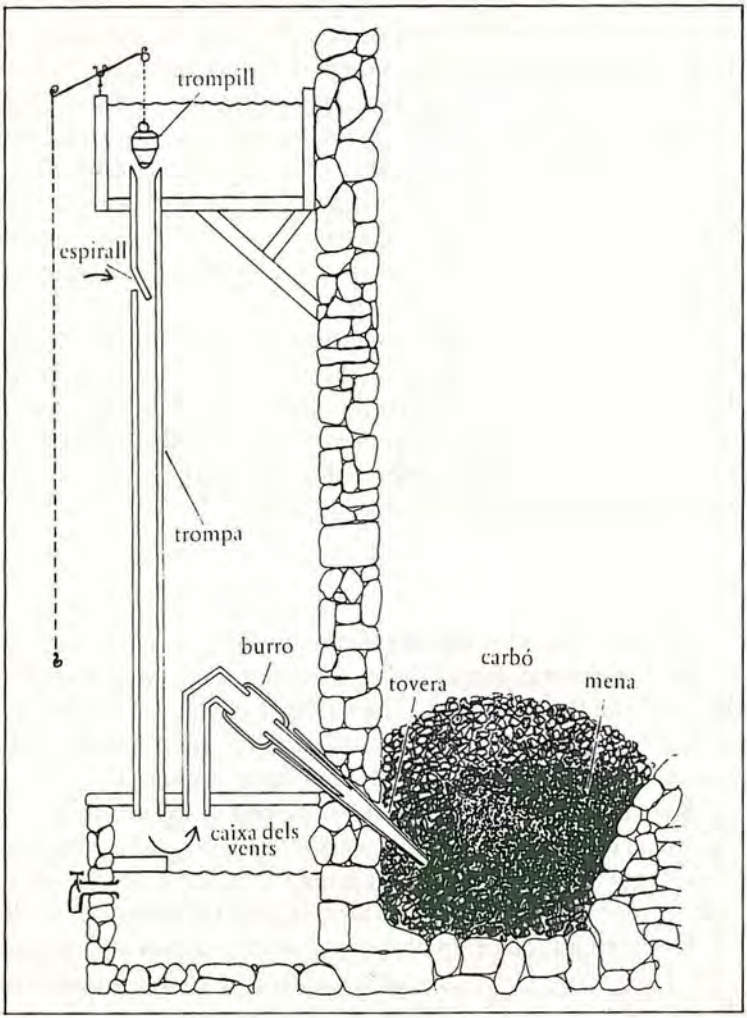


*Figure 1*

Sketch of the water nozzle used in the Farga Catalana to inject air to the furnace, in which the relative position of the charcoal and of the mineral is shown on starting the reduction.

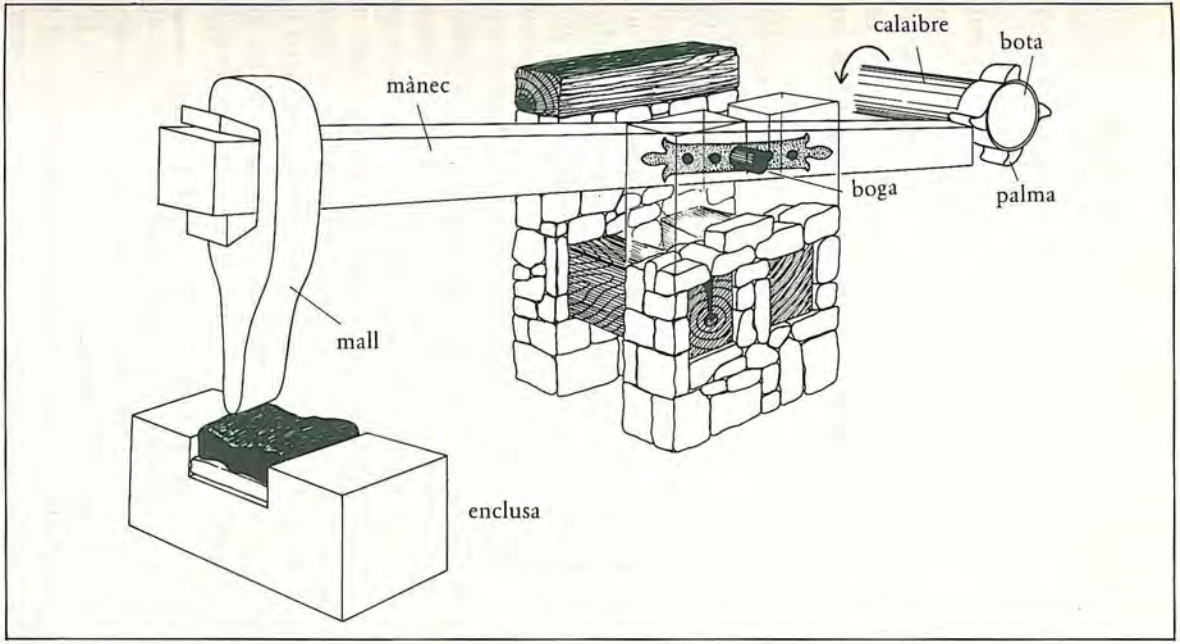


*Figure 2*

Sketch of a drop hammer. The water from the dam falls over the blades of the hydraulic wheel, which moves the «calaibre», when this axle rotates the «palmas» of the «bota» push down the handle of the «mall» which rises, then falls onto the anvil.

## Raw materials

The «Farga Catalana» needed as raw material, mineral and coal. The mineral, or more correctly, the concentrated ore suitable for the Farga Catalana process, was limonite, or hydrated oxide of irom, found in the Eastern Pyrenees. If this type of mineral was not available ferric oxide, oligist, was used, after a hydrating treatment consisting of concentration, crushing and exposure outdoors for a few days, spread out on the ground. The ore bodies exploited by the Fargas were rather poor. Information on the benefication of iron ores is available for numerous Catalan zones.

The fuel and reductant used in the Farga process was charcoal made from pine and beech wood. The carbonization of the wood was accomplished by burning it with insufficient air. Tree trunks, cut in short lengths, were piled up and covered with a layer of soil, with holes made in the lower part and on top for the entrance and exit of air. Once the fire was lit with very dry branches, the carbonizing process proceeded, burning small amounts of lignite and cellulose. The evolution of this process could be followed from the outside by taking note of the fumes coming off. Experimentally, it may be observed that on heating wood at temperatures above 100°C water vapor comes off in the form of white fumes. By heating wood in the temperature range 120-500°C, the fumes are blue, since at these temperatures pyroligneous acid, a mixture of phenol and guaiacol, is given off. The end of the process is when no more fumes are given off, since then the charcoal will start to burn. The charcoal is, then, the product resulting from this incomplete combustion of wood. It is a dark substance, brittle, fibrous, with few salts and high in carbon content.

The importance of charcoal to the Farga Catalana is obvious from the placement of these installations: near large woods rather than near the ore bodies. This is logical, if one considers that for each ton of iron produced, larger amounts of charcoal were needed than of mineral. On the other hand, the price was the inverse;

a ton of mineral was more expensive than a ton of charcoal. A document of the XVII century, signed in Ripoll, quotes at 6 gold «doblas», the use for 15 years of a pine woods.

All Fargas which we have found were located next to river, which supplied water, via a reservoir, to feed both the water nozzle and the water wheel.

## Operation

The «Fargues» operated (Figure 3) with a specialized personnel team under an «*administrador*», a position equivalent to that of a manager in today's firms; he was in charge of purchasing raw materials, the sale of the metal produced and employment of personnel. Generally, he was also the owner of the Farga. The technical part was the responsibility of the «*foguer*», a position equivalent to that of the superintendent of today's steel plants. He took care of the construction and repair of the furnace and tuyeres, and he controlled the quality of the products made. The Farga personnel rested on Sundays, although on this day towards evening the «*escola*» and his helper took care to light the charcoal in the furnace so that on Monday it was sufficiently warm to be charged with mineral. The person in charge of mineral preparation was the «*picamera*».

The operation of ore reduction was started by covering the bottom of the furnace with charcoal powder, which was lit. Then, once the furnace was hot, a layer of larger pieces of charcoal was added. Immediately, a steel plate was placed parallel to the «*porgues*» in the center of the furnace; this permitted placement of a vertical layer of carbon on the tuyere side and a layer of mineral on the other side of the plate. Then the plate was removed and the upper part of the mineral bed was covered with a layer of small pieces of moist carbon and slag, so that the outside surface had a spherical shape and would concentrate the flames. Immediately air was blown in through the tuyeres and after one and

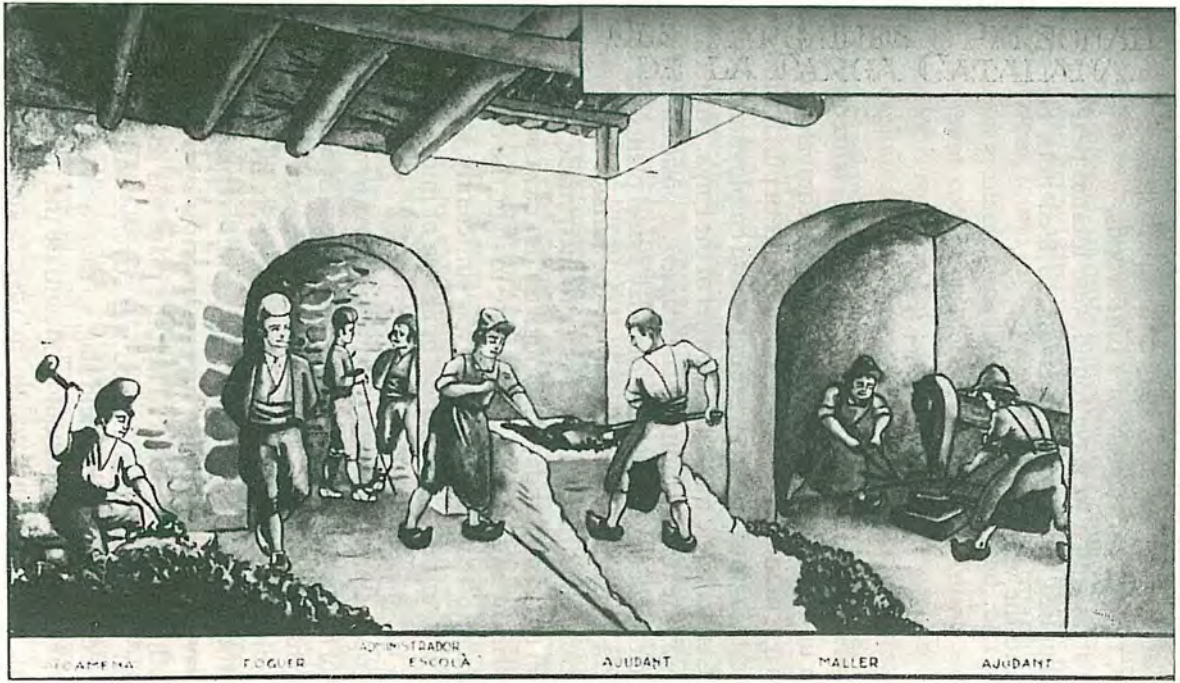


*Figure 3*

The personnel of the Farga Catalana in their characteristic working attitude. A watercolor by V. Serra, who was an eyewitness to the operation of this process.

half hours of operation it was possible to obtain temperatures above 1200°C. Over a period of 3 or 4 hours mineral and carbon were added, while in the meantime, through the «lleteirol», liquid slag was removed. If the slag was very viscous it was reintroduced into the furnace because it was rich in iron. The end of the operation was when at the bottom of the furnace was found an irregular ball of about 100 kg of iron, or low carbon steel, with slag inclusions and pores — «*el masser*». At this moment started the most spectacular operation at the Farga: the removal of the «*masser*» from the furnace and its transport to the drop hammer. This operation required the use of all the personnel of the Farga. The purpose of the drop hammer equipment, which operated under the direction of the «*maller*» was threefold: to eliminate the slag from the «*masser*», to make it more compact and to shape it. The «*masser*» had to be forged while it was still hot from the furnace. Normally the compaction was done in one drop hammer and the shaping in another.

The output of the operation was low since to obtain 100 kg of metal required more than 300 kg of mineral and more than 400 kg of charcoal.

The metal obtained was classified according to quality and the extent of the shaping. As to quality it was divided into «*ferro comú*» (iron) and «*ferro bo*» (steel). The latter was a low carbon steel, which was harder, of higher strength and lower ductility. It was obtained by allowing the «*ferro comú*» to stay longer in the furnace surrounded by incandescent carbon, with the precaution that the iron mass would not be in contact with the atmosphere.

According to whether or not it was forged, the product was classified as «*batut*» and «*buidat*». Depending on the dimensions of the forged section, the «batut» was classified as: (a) «*Verga o vergalina*»: a round section used for weapons and nails; (b) «*Barrot*»: a square section with a three finger cross section; (c) «*Llaunes*»: a rectangular section, 3 fingers wide and one finger thick; (d) «*Cairal*»: a square section one finger thick.

## Theory

The «Farga Catalana» process, judged by the quality of the products obtained, was a fairly high tecnology, although it had been developed by metallurgical art transmitted from masters to apprentices through the Middle Ages and modern times. The following is a scientific interpretation of that technology. The great intuition of the artisans of that time surprises us. We shall comment on the major concepts.

The operation done by the «*picamena*» (ore crusher) consisted of grinding the concentrate and then heating it in a carbon furnace placed outside the Farga building. The objective of this calcination was to transform the limonite or the hydrated oligist into solid, very porous iron oxide with large specific surface. Water vapor was eliminated into the air. Siderite ore, very rare in the Oriental Pyrenees, was changed into ferrous oxide, a porous solid, and carbon dioxide gas which went into the atmosphere. Porous solids were desirable since the speed of reduction depended on the specific surface of the ore.

The particular relative position, in vertical layres, of carbon and the ore on starting the operation in the Farga Catalana furnace was to obtain the maximum possible amount of carbon monoxide in front of the entrance of the tuyere and then to direct this towards the ore. In this way the ferric oxide was reduced to ferrous oxide, and finally to iron. The reductant was oxidized to carbon dioxide, which escap ed into the atmosphere.

Simultaneously with the reduction process, carburizing and slagging reactions took place. At above 910°C, face centered cubic iron is able to dissolve carbon from the dissociation of carbon monoxide into carbon and carbon dioxide, transforming iron into steel. At the same time impurities in the iron ore, such as silicates and carbonates, were slagged off. When the furnace reached a temperature between 700 and 800°C the ferrous oxide and the manganese oxide in the ore reacted with silica to from a fairly

fluid iron and manganese silicate slag which was separated from the iron, since it was less dense and could easily be poured through the «lleteirol». At temperatures above 900°C calcium carbonate, a gangue very frequent in the iron ores of the Catalan Pyrenees, underwent decomposition into calcium oxide and carbon dioxide. The calcium oxide reacted with the silica to produce a calcium silicate slag, more stable than the iron and manganese silicates. For this reason when calcium silicate was present in the slag, ferrous and manganese oxides remained in part the slag, and in part were reduced so that iron and manganese were incorporated into the «*masser*» (ingot).

Sulfur is usually an undesirable element in steel, since it causes embrittlement. Sulfur present in the «*masser*» originated in the carbon cinders and was concentrated in the nonmetallic inclusions of the microstructure.

Phosphorus is another chemical element which embrittles steel. In the iron products of the Farga Catalana there is little of this element present, although calcium orthophosphate usually is present in the iron ores of the Oriental Pyrenees. At the temperature of the furnace of the Farga Catalana the calcium orthophosphate can decompose into diphosphorus pentoxide which is reduced by carbon monoxide, with phosphorus dissolving in the iron. However in the slag of this type of furnace there are sufficient amounts of calcium oxide to displace the reaction to the formation of calcium orthosphosphate which goes into the slag. As a result the reduction of the disphosphorus pentoxide and the phosphorization of the iron is minimized.

Slag found in the neighbourhood of the meeting of the rivers Ter and Costabona, the location of the «*Farga Setcases*» (Ripollès) has been found to contain 63% iron oxide and 1.2% calcium fluoride. Such a high percentage of iron in the slag was normal for the Farga Catalana process, and was one of the decisive factors in its decline. However, the calcium fluoride content of the slag improved the quality of its end products, since it behaved as a flux, reducing considerably the melting point of the slag.

At present the «Farga Catalana» belongs to the past of Catalonia, and is an important constituent of the historic introductions which usually are present in the first pages of modern steel-making books. This process was a great innovation in its time because of the introduction of the water nozzle to inject air into the furnace, producing a more constant blast than that produced in other processes. The blast furnace, appearing towards the second half of the XVIII century, gradually replaced the «Farga Catalana» process, which by 1878 had disappeared altogether. However, at present new processes are being developed to produce iron directly, which, of course, is a logical way to proceed. Their product, sponge iron, is very similar to the «*masser*» from the «Farga Catalana»

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