The Role of Muslim Mechanical Engineers In Modern Mechanical Engineering

Dedicate to12th Century Muslim Mechanical Engineer

And

Mechanical Genius *Badi Al-Zaman AbulI-Ezz Ibn Ismail Ibn Al-Razzaz Al-Jazari* Who laid down the foundation of Engine and Modern Mechanical Engineering.

A Project Report For B-TECH (Mechanical Technology)

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Islam's Contribution to Europe's Renaissance and Modern Science.

We have understood the importance of 800 years of Islamic society and culture in Spain between the 8th and 15th centuries. The contribution of Muslim Spain to the preservation of classical learning during the Dark Ages, and to the first flowering of the Renaissance. Not only did Muslim Spain gather and preserve the intellectual content of ancient Greek and Roman civilization, it also interpreted and expanded upon that civilization, and made a vital contribution of its own in so many fields of Science and Technology- in astronomy, mathematics, algebra (itself an Arabic word), law, history, medicine, pharmacology, optics, agriculture, architecture, theology, music. Engineering.

Islam nurtured and preserved the quest for learning. In the words of the Prophet's PBUH "the *ink of the scholar is more sacred than the blood of the martyr."* Cordoba in the 10th century was by far the most civilized city of Europe. We know of lending libraries in Spain at the time King Alfred was making terrible blunders with the culinary arts in this country. It is said that the 400,000 volumes of its ruler's library amounted to more books than all of the rest of Europe put together. That was made possible because the Muslim world acquired from China the skill of making paper more than four hundred years before the rest of non-Muslim Europe. Many of the traits on which Europe prides itself came to it from Muslim Spain. Diplomacy, free trade, open borders, the techniques of academic research, of anthropology, etiquette, fashion, alternative medicine, hospitals, all came from this great city of cities. Mediaeval Islam was a religion of remarkable tolerance for its time, allowing Jews and Christians to practice their inherited beliefs, and setting an example which was not, copied for many centuries in the West.

Industry

The Abbasid Caliph Haroun-al-Rashid sent Charlemagne in Aix from Baghdad a present of a clock made by his horologists which struck a bell on the hour very hour, to the great wonder and delight of the whole court of the newly crowned Holy Roman Emperor.

The massacre and expulsion of the Muslims of Andalusia by the Christians carried with it the closure of many of the great factories that has existed under Islamic rule, and the standstill of progress that had been made in science, crafts, arts, agriculture, and other products of civilization. Towns began to fall into ruin because of the lack of skilled masons. Madrid dropped from 400,000 to 200,000 inhabitants: Seville, which had possessed 1,600 factories under the Muslims, lost all but 300, and the 130,000 workers formerly employed had no more jobs, while the census of Philip IV showed a fall of 75% in population figures.

It was the Muslims also who brought about the substitution of cotton-wove paper for the old parchments; and it was this invention which formed the basis for Europe's later invention of printing, using an old Chinese technique, and so for the vast uprush of learning which came with the Renaissance. More, since monks were starved for parchment on which to write their religious works, they were tending more and more to scrape off priceless ancient scientific texts from old parchments and to use them again as palimpsets. The introduction of paper put a stop to this disastrous practice in time to save quite a number of texts which would have otherwise been lost for ever, as, alas, too many were.

A paper manuscript of the year AD 1009 was found in the Escorial library, and claims to be the oldest hand-written book on paper still in existence. Silk-wove paper, of course, was a Chinese invention, since silk was native to China though rare in Europe; and the Musulman genius lay in seeing the possibility of substituting cotton for silk, and so giving Europe a plentiful supply of a practicable material for the reproduction of books by the monkish scribes.

Philip Hitti writes in his "History of the Arabs" that the art of road-making was so well developed in Islamic lands that Cordova had miles of paved road lit from the houses on each side at night so that people walked in safety; while in London or Paris anyone who ventured out on a rainy night sank up to his ankles in mud - and did so for seven centuries after Cordova was paved! Oxford men then held that bathing was an idolatrous practice; while Cordovan students revelled in luxurious public hammams(bathroom) !

Chemistry

Jaber ibn Haiyan, disciple of the sixth Imam Jafar-i-Sadiq, became known world-wide as "the Father of Chemistry" and of Arab alchemy. His influence on western chemistry and alchemy was profound and long-lasting. Some hundred of his works survive. Of him the late Sayyid Hebbat-ud-Din Shahristani of Kadhemain, once Iraq's Minister of Education, writes: "I have seen some 50 ancient MSS of works of Jaber all dedicated to his master Imam Ja'afar. More than 500 of his works have been put into print and are for the most part to be found among the treasures of the National libraries of Paris and Berlin, while the savants of Europe nickname him affectionately 'Wisdom's Professor' and attribute to him the discovery of 19 of the elements with their specific weights, etc. Jaber says all can be traced back to simple basic particle composed of a charge of lightning (electricity) and fire, the atom, or smallest indivisible unit of matter, very close to modern atomic science.

The blending of colouring matters, dyeing, extraction of minerals and metals, steelmaking, tanning, were amongst industrial techniques of which the Muslims were early masters. They produced Nitric Acid, Sulphoric acid, Nitro-glycerin, Hydrochloric Acid, Potassium, Aqua Ammonia, Sal Ammoniac, Silver Nitrate, Sulphoric Chloride, Potassium Nitrate, Alcohol, Alkali (both still known by their Arabic names), Orpiment (yellow tri-sulphide of arsenic; arsenic is derived from the Persian zar = gold, adjective zarnee = golden, Arabised with article "al" to "al-zernee" pronounced "azzernee" and so taken into Greek where was turned to the recognizable word "arsenikon" which means "masculine" since the gold colour was supposed to link it with the sun, a musculine diety!): and finally - though this does not close the list we might cite - Borax, also an Arabic word - Booraq. Further, the arts of distilling, evaporation, sublimation, and the use of Sodium, Carbon, Potassium Carbonate, Chloride, and Ammonium were common under the Abbasid Caliphate.

Mathematics

Baron Carra de Vaux Author of the chapter on "Astronomy and Mathematics" in "The Legacy of Islam" (OUP 1931 pp. 376-398), points out that the word "algebra" is a Latinisation of the Arabic term Al-jabr (= "i.e. of complicated numbers to a simpler language of symbols)., thereby revealing the debt the world owes to the Arabs for this invention. Furthermore the numerals that are used are "Arabic numerals" not merely in name but also in fact. Above all Arabs' realisation of the value of the Hindu symbol for zero laid the foundation of all our modern computerised technology. The word "zero", like its cousin "cipher" are both attempts at transliterating the Arabic "sefr", in order to convoy into Europethe reality and the meaning of that word in Arabic.

De Vaux writes: "By using ciphers the Arabs became the founders of the arithmetic of everyday life; they mada algebra an exact science and developed it considerably; they laid the foundations of analytical geometry; they were indisputably the founders of plane and spherical trigonometry. The astrolabe (safeeha) was invented by the Arab Al-Zarqali (Arzachel) who lived in Spain AD 1029-1087. The word "algorism" is a latinisation of the name of his home province Al-Khwarizmi. The Arabs kept alive the higher intellectual life and the study of science in a period when the Christian West was fighting desperately with barbarism".

This is not the place to go further into Muslim achievements in mathimatics and astronomy. Suffice it to refer once again to the Jalali calendar of Omar Khayyam, with its formulae for exact calculation of the timing of the earth's orbits round the sun, to which reference has been made earlier.

Role of "Islamic" Mechanical Engineering in Modern Mechanical Engineering.

Donald R. Hill, a retired engineer, became interested in Arabic while serving with Britain's Eighth Army in North Africa during World War II. After the war, he worked for the Iraq Petroleum Company, returning to England to join Imperyal Chemical Industries. He later moved to senior positions in the subsidiaries of two U.S. petrochemical corporations, from which he retired in 1984. He now devotes his time to Arabic studies, in which he has earned a master's degree from Durham University and a Ph.D. from the University of London's School of Oriental and African studies. His translation of Al-Jazari's book of mechines won for him a share of the 1974 Dexter Prize, awarded by the American Society for the History of Technology.

The West is accustomed to seeing its own intellectual development as having been shaped, in the main, by internal factors. This view of history traces our heritage back from the Industrial Revolution to the Enlightenment and Renaissance and, thence, via the monkish scribes of the Middle Ages, to the fountainhead: Greece, Rome and the ancient empires of the Fertile Crescent.

But the picture is incomplete because it ignores the intermediation of the civilization of Greek Christendom (or Byzantium), Hindu India, Confucian China and Islam. Our subject here is the technology of medieval Islam - the knowledge it preserved, the new ideas it contributed to the medieval world and the inventions by which it anticipated later developments.

When the prophet Muhammad (PBUH) died in A.D. 632, he left behind a new religion with its administrative centre at Medina and its spiritual heart at Mecca. Within about a year of his death the rest of Arabia had joined the Muslim fold; by 750 the Arab Empire stretched from the Pyrenees to central Asia.

Although the advent of Islam brought immense political, religious and cultural changes, the technological traditions were largely unaffected. In mechanical engineering the Muslims adapted the techniques of earlier civilizations to satisfy the needs of the new society. These needs centered on a city life more extensive than any seen since Roman times.

Baghdad's population is estimated to have reached about 1.5 million in the 10th century, and cities such as Cordoba, Cairo and Samarkand, although smaller, were still of considerable magnitude. Paris, by contrast, would not number 100,000 souls for another 400 years. Feeding and clothing the inhabitants of the Islamic world's vast urban centers placed great demands on agriculture and distribution. These, in turn, depended on technology for supplying irrigation water to the fields and for processing the crops into foodstuffs.

Water and water power, therefore, will constitute our first concern. Then we shall describe water mills. Finally, we shall turn to descriptions, most of them in a handful of treatises that have come down to us, of water clocks, fountains and various automata, some of which might seem trivial to modern eyes. Yet they exploit concepts, components and techniques that did not enter the armamentarium of European engineering until the time of the Renaissance.

The most ancient water-raising machine is the shaduf, a counterweighted lever from which a bucket is suspended into a well or stream. It appears in illustrations from as early as 2500 B.C. in Akkadin reliefs and is still in use today in parts of the Middle East. Other traditional water-raising machines, introduced between the third and first centuries B.C., include the screw, or water snail, whose invention is attributed to the great mathematician Archemides. It consists of a helical wooden blade rotating within a barrellike wooden cylinder, a design that could not push water up inclines greater than about 30 degrees, although 20 degrees was more common.

Higher lift was achieved by the noria, a large wheel driven by the velocity of the current. On the outer rim a series of compartments are fitted in between a series of paddles that dip into the water and provide the propulsive power. The water is scooped up by the compartments, or pots, and is discharged into a head tank or an aqueduct at the top of the wheel. Norias could be made quite large. The well-known whells at Hama on the river Orontes in Syria have a diameter of about 20 meters. The noria is self-acting, and its operation thus requires the presence of neither man nor beast. It is, however, expensive to build and maintain.

The "saqiya" is probably the most widespread and useful of all the water-raising machines that medieval Islam inherited and improved. It is a chain of pots driven by one or two animals by means of a pair of gears. The animals push a drawbar through a circle, turning an axle whose pinion meshes with a vertical gear. The gear carries a bearing for the chain of pots, or pot garland - two ropes between which earthenware pots are suspended. The chain of pots is optimal for raising comparatively small amounts of water from comparatively deep wells.

Other mechanisms, however, were required to raise large quantities of water relatively small distances. The problem can be solved by using a spiral scoop wheel, which raises water to the ground level with a high degree of efficiency. The machine is very popular in Egypt nowadays, and engineers at a research laboratory near Cairo have been trying to improve the shape of the scoop in order to achieve the maximal output. Although it appears very modern in design, this is not the case; a 12th-century miniature from Baghdad shows a spiral scoop wheel driven by two oxen.

These machines are still in use in many oil-poor middle eastern countries, because for many purposes they are at least as efficient as diesel-driven pumps. Moreover, they do not require imported fuels, spare parts or labor. Vital time can therefore be saved, when the loss of even a single day's operation of a machine can kill a crop, making reliable performance literally a matter of life and death.

Given the importance of water-raising devices to the economy of many Islamic societies, it is hardly surprising that attempts were made to introduce new designs or modify existing ones. Some of the most interesting innovations are found in one section of Ibn Al-Razzaz Al-Jazari's great book, The book of knowledge of Ingenious Mechanical Devices, which was completed in Diyar Bakr in Upper Mesopotamia in 1206 AD.

From our point of view, the most significant aspect of these machines is the ideas and components that they embody. For example, one of them is explicitly designed to eliminate out-of-balance loading and so produce a smoother operation. Another incorporates a crank, the first known example of the non-manual use of this important component. Some of these devices functioned as curiosities.

The invention containing the most features of relevance for the development of mechanical design, however, was intended as a practical machine for high-lift duties: a twin cylinder, water-driven pump. A stream turned a paddle wheel meshing with a horisontal gear wheel, which was installed above a sump that drained into the stream. The horisontal wheel contained a slot into which a vertical pin fitted near the perimeter of the wheel.

The turning wheel moved two connecting rods back and forth, thus driving opposing pistons made of copper disks spaced about six centimeters apart, the gap being packed with hemp. The pistons entered copper cylinders, each one having a suction and delivery pipe. One piston began its suction stroke while the other began its delivery stroke. This machine is remarkable for three reasons: it incorporates an effective means of converting rotary into reciprocating motion, it makes use of the double-acting principle and it is the first pump known to have had true suction pipes.

Waterpower was clearly a prominent concern of medieval Islamic planners. Whenever they mentioned a stream or river, for example, they often included an estimate of how many mills it would operate. One might say that they assessed streams for "mill power"

WATER MILLS

The three main types of waterwheel had all been in existence since Classical times - the horizontals wheel and two variations of the vertical wheel. The horizontal wheel has vanes protruding from a wooden rotor, onto which a jet of water is directed. In modern Europe the design was altered to use water moving axially, like air flowing through a pinwheel, creating the water turbine. Interestingly, wheels with curved blades onto which the flow was directed axially are described in an Arabic treatise of the ninth century.

The more powerful vertical wheels came in two designs: undershot and overshot. The former is a paddle wheel that turns under the impulse of the current. The overshot wheel receives water from above, often from specially constructed channels; it thus adds the impetus of gravity to that of the current.

When the levels of rivers fall in the dry season, and their flow diminishes, undershot wheels lose some of their power. Indeed, if they are fixed to the banks of rivers, their paddles may cease to be immersed. One way this problem was avoided by mounting the waterwheels on the piers of bridges and taking advantage of the increased flow there. Another common solution was provided by the ship mill, powered by undershot wheels mounted on the sides of ships moored in midstream. On the rivers Tigris and Euphrates in the 10th century, in Upper Mesopotamia, which was the granary for Baghdad, enormous ship mills made of teak and iron could produce 10 tons of flour from corn in every 24-hour period.

Grist milling - the grinding of corn and other seeds to produce meal - was always the most important function of mills. Mills were, however, put to many other industrial uses. Among these applications were the fulling of cloth, the crushing of metallic ores prior to the extraction process, rice husking, paper making and the pulping of sugarcane. The usual method of adapting waterwheels for such purposes was to extend the axle and fit cams to it. The cams caused trip-hammers to be raised and then released to fall on the material.

WINDMILLS

Where waterpower was scarce, the Muslims had recourse to the wind. Indeed it was in river less Siesta, now in the western part of Afghanistan, that windmills were invented, probably early in the seventh century A.D. The mills were supported on substructures built for the purpose or on the towers of castles or the tops of hills. They consisted of an upper chamber for the millstones and a lower one for the rotor. A vertical axle carried either 12 or six rotor blades, each covered with a double skin of fabric. Funnel-shaped ducts pierced the walls of the lower chamber, their narrower ends facing toward the interior in order to increase the speed of the wind when it flowed against the sails.

This type of windmill spread throughout the Islamic world and thence China and India. In medieval Egypt it was used in the sugarcane industry, but its main application was to grist milling.

FINE TECHNOLOGY

Now we turn to a type of engineering that is quite different from the utilitarian technology described so far. We may perhaps call it fine technology, since its distinguishing features derive from the use of delicate mechanisms and controls.

Some of these devices had obvious practical uses: water clocks were used in astronomical observations and were also erected in public places; astronomical instruments aided both observation and computation. Other gave amusement and aesthetic pleasure to the members of courtly circles. Still others undoubtedly had didactic purposes, for example, to demonstrate the principles of pneumatics as understood at the time. Apart from astronomical instruments and the remains of two large water clocks in Fez, Morocco, none of theses machines has survived. Our knowledge of them comes almost entirely from two of Arabic treatises that have come down to us.

The first is by the Bano (Arabic for sons of) Musa, three brothers who lived in Baghdad in the ninth century. They were patrons of scholars and translators as well as eminent scientists and engineers in their own right. They undertook public works and geodetic surveys and wrote a number of books on mathematical and scientific subjects, only three of which have survived.

The one that concerns us here is "The Book of Ingenious Devices". It contains descriptions, each with an illustration, of 100 devices, some 80 of which are trick vessels of various kinds. There are also fountains that change shape at intervals, a "hurricane" lamp, self-trimming and self-feeding lamps, a gas mask for use in polluted wells and a grab for recovering objects from the beds of streams. This last is of exactly the same construction as a modern clamshell grab.

The trick vessels have a variety of different effects. For example, a single outlet pipe in a vessel might pour out first wine, then water and finally a mixture of the two. Although it cannot be claimed that the results are important, the means by which they were obtained are of great significance for the history of engineering. The Banu Musa were masters in the exploitation of small variations in aerostatic and hydrostatic pressures and in using conical valves as "in-line" components in flow systems, the first known use of conical valves as automatic controllers.

In several of these vessels, one can withdraw small quantities of liquid repeatedly, but if one withdraws a large quantity, no further extractions are possible. In modern terms, one would call the method used to achieve this result a fail-safe system.

The second major treatise to have come down to modern times was written by Al-Jazari at the close of the 12th century. He was a servant of the Artuqid princes, vasals of Saladin (who vanquished Richard the Lion Heart during the Third Crusade). His work places him in the front rank of mechanical engineers from any cultural region in pre-Renaissance times.

Several of Al-Jazary's machines have been reconstructed by modern craftsmen working from his specifications, which provided far more detail than was customary in the days before patent law was invented. Such openness has rarely been encountered until recent times.

WATER CLOCKS

Al-Jazari's clocks all employed automata to mark the passage of the hours. These included birds that discharged pellets from their beaks onto cymbals, doors that opened to reveal the figures of humans, rotating Zodiac circles, the figures of musicians who struck drums or played trumpets and so on. Generally speaking, the prime movers transmitted power to these automata by means of pulley systems and tripping mechanisms. In the largest of the water clocks, which had a working face of about 11 feet high by 4.5 feet wide, the drive came from the steady descent of a heavy float in a circular reservoir.

Clearly, some means of maintaining a constant outflow from the reservoir was needed and was indeed achieved in a most remarkable way. Apipe made of cast bronze led out from the bottom of the tap, and its end was bent down at right angles and formed into the seat of a conical valve. Directly below this outlet sat a small cylindrical vessel in which there bobbed a float with the valve plug on its upper surface.

When the tap opened, water ran into the float chamber, the float rose and caused a plug to enter the valve's seat. Water was thus discharged from a pipe at the bottom of the float chamber, and the valve opened momentarily, whereupon water entered from the reservoir, the valve closed momentarily and so on. An almost constant head was therefore maintained in the float chamber by feedback control, and the large float in the reservoir descended at constant speed. Al-Jazari said he got the idea for his invention from a simpler version which he attributed to Archimedes.

This clock did not record equal hours of 60 minutes each, but temporal hours, that is to say, the hours of daylight or darkness were divided by 12 to give hours that varied with the seasons. This measurement required another piece of equipment: the pipe from the float chamber leading into a flow regulator, a device that allowed the orifice to be turned through a complete circle and thus to vary the static head below the surface of the water in the reservoir. Previous flow regulators had all been inaccurate, but Al-Jazari describes how he calibrated the instrument accurately by painstaking tiAl-and-error methods. Another type of clock, which may have been Al-Jazari's own invention, incorporates a closed-loop system: the clock worked as long as it was kept loaded with metal balls with which to strike a gong.

CANDLE CLOCKS

Al-Jazari also describes candle clocks, which all worked on a similar principle. Each design specified a large candle of uniform cross section and known weight (they even laid down the weight of the wick). The candle was installed inside a metal sheath, to which a cap was fitted. The cap was made absolutely flat by turning it on a lathe; it had a hole in the centre, around which, on the upper side, was an indentation.

The candle, whose rate of burning was known, bore against the underside of the cap, and its wick passed through the hole. Wax collected in the indentation and could be removed periodically so that it did not interfere with steady burning. The bottom of the candle rested in a shallow dish that had a ring on its side connected through pulleys to a counterweight. As the candle burned away, the weight pushed it upward at a constant speed. The automata were operated from the dish at the bottom of the candle. No other candle clocks of this sophistication are known.

MISCELLANEOUS

Other chapters of Al-Jazari's work describe fountains and musical automata, which are of interest mainly because in them the flow of water alternated from one large tank to another at hourly or half-hourly intervals. Several ingenious devices for hydraulic switching were used to achieve this operation. Mechanical controls are also described in chapters dealing with a potpourri of devices, including a large metal door, a combination lock and a lock with four bolts.

We see for the first time in Al-Jazari's work several concepts important for both design and construction: the lamination of timber to minimize warping, the static balancing of wheels, the use of wooden templates (a kind of pattern), the use of paper models to establish designs, the calibration of orifices, the grinding of the seats and plugs of valves together with emery powder to obtain a watertight fit, and the casting of metals in closed mold boxes with sand.

CONCLUSIONS

Previously how Islamic mechanical technology entered Europe is unknown. Indeed, there may be instances of ideas being inherited directly from the Greco-Roman tradition into medieval Europe. Nor can we rule out cases of reinvention. When allowances have been made, however, it seems probable that some elements of the rich vein of Islamic mechanical engineering were transmitted to Europe.

Any such technological borrowing would probably have been mediated by contacts between craftsmen, by the inspection of existing machines working or in disrepair and by the reports of travelers. The most likely location for the transfer of information was Iberia during the long years in which Christians and Muslims coexisted.

The diffusion of the elements of machine technology from lands of Islam to Europe may always remain partly conjectural. This should not in any way be allowed to devalue the achievements of the Muslim engineers, known and anonymous. Nor should we overemphasize the relevance of the Islamic inventions to modern machinery. Of equal or great importance is the contribution they made to the material wealth, and hence the cultural riches, of the medieval Near East.

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Fine Technology

The expression 'fine technology', embraces a whole range of devices and machines, with a multiplicity of purposes: water clocks, fountains, toys and automata and astronomical instruments What they have in common is the considerable degree of engineering skill required for their manufacture, and the use of delicate mechanisms and sensitive control systems. Many of the ideas employed in the construction of ingenious devices were useful in the later development of mechanical technology.

The tradition of pre-Islamic fine technology continued uninterrupted under Islam and was developed to a higher degree of sophistication. Monumental water clocks in Syria and Mesopotamia continued to be installed in public places. The Abbasid Caliphs were interested in clocks and ingenious devices. The story of the clock that was presented by Harun al-Rashid (786-809), to Charlemagne in 807 AD is well known.

Feedback Control and Automata

Feedback control is an engineering discipline. As such, its progress is closely tied to the practical problems that needed to be solved during any phase of human history.

The Book of Ingenious Devices (*Kitab al-Hiyal*) of Banu Musa, was written in Baghdad about 850. It contains descriptions of a hundred devices, most of which are trick vessels which exhibit a bewildering variety of effects. The trick vessels have a variety of different effects. For example, a single outlet pipe in a vessel might pour out first wine, then water and finally a mixture of the two. The means by which these effects were obtained are of great significance for the history of engineering.

By the end of the tenth century, the construction of automata was probably a well-established practice in the Arabic world. There is historical evidence that the skills of automata makers were enlisted to add distinctive features to royal palaces.

The early history of automata in Europe goes back to Arabic automata in Muslim Spain. We have mentioned how the technology of water clocks had been transferred to Western Europe. The elaborate automata of Islamic water clocks became a feature of European water clocks also.

The Banu Musa used conical valves as "in-line" components in flow systems, the first known use of conical valves as automatic controllers. An almost constant head was maintained in a float chamber by feedback control.

Other Muslim engineers used the float regulator and the important feedback principle of "on/off control in their water clocks and automata.

As mentioned above, water clocks spread in Europe for some time before they were replaced by mechanical clocks, and it follows that European engineers and technicians were acquainted also to the float regulators and the automata that accompanied them.

In the late 1700's, regulation of the level of a liquid was needed in two main areas: in the boiler of a steam engine and in domestic water distribution systems. Therefore float regulator devices once again become popular during the Industrial Revolution.

The important feedback principle of "on/off control that was used by Muslim engineers came up again also in connection with minimum-time problems in the 1950's.

The Evolution from Water to Mechanical Clocks

The technology of clock- making was transferred to Muslim Spain. About the year 1050 AD, al-Zarqali constructed a large water clock on the banks of the Tagus at Toledo in Spain. The clock was still in operation when the Christians occupied Toledo in 1085 AD.

A manuscript describing Andalusian monumental clocks was written in the eleventh century by Ibn Khalaf al-Muradi. Most of his devices were water clocks, but the first five were large automata machines that incorporated several significant features. Each of them, for example, was driven by a full-size water wheel, a method that was employed in China at the same period to drive a very large monumental water clock. The text mentions both segmental and epicyclical gears. (In segmental gears one of a pair of meshing gear-wheels has teeth on only part of its perimeter; the mechanism permits intermittent transmission of power). The illustrations clearly show gear-trains incorporating both these types of gearing. This is extremely important: we have met simple gears in mills and water-raising machines, but this is the first known case of complex gears used to transmit high torque. It is also the earliest record we have of segmental and epicyclical gears. In Europe, sophisticated gears for transmitting high torque first appeared in the astronomical clock completed by Giovanni de Dondi about AD 1365.

In a Spanish work compiled for Alfonso X in 1277 AD, in which all the chapters are translations or paraphrases of earlier Arabic works we find a description of a clock. It consisted of a large drum made of wood tightly assembled and sealed. The interior of the drum was divided into twelve compartments, with small holes between the compartments through which mercury flowed. Enough mercury was enclosed to fill just half the compartments. The drum was mounted on the same axle as a large wheel powered by a weight-drive wound around the wheel. Also on the axle was a pinion with six teeth that meshed with thirty-six oaken teeth on the rim of an astrolabe dial. The mercury drum and the pinion made a complete revolution in 4 hours and the astrolabe dial made a complete revolution in 24 hours. Clocks incorporating this principle are known to work satisfactorily, since many of them were made in Europe in the seventeenth and eighteenth centuries. This type of timepiece, however, with its effective mercury escapement, had been known in Islam since the eleventh century, at least 200 years before the first appearance of weight-driven clocks in the West.

An important aspect of Islamic fine technology is the tradition of geared astronomical instruments which were described in Arabic literature. The most notable example is the astronomical geared mechanism that was described by al-Biruni and called by him *Huqq al-Qamar* (Box of the Moon). From al Biruni's text we understand that these mechanisms were known in Islamic astronomy. A surviving example is the geared calendar dated 1221/2 AD that is part of the collection of the Museum of the History of Science at Oxford.

Derek J. de Solla Price when describing the Antikythera mechanism (90 AD) remarked that "It seems likely that the Antikythera tradition was part of a corpus of knowledge that has since been lost but was known to the Arabs. It was developed and transmitted by them to medieval Europe, where it became the foundation for the whole range of subsequent invention in the field of clockwork

Many of the ideas that were to be embodied in the mechanical clock had been introduced centuries before its invention: complex gear trains, segmental gears in al-Muradi and al-Jazari; epicycle gears in al-Muradi, celestial and biological simulations in the automata-machines and water clocks of Hellenistic and Islamic engineers; weight-drives in Islamic mercury clocks and. pumps, escapements in mercury docks, and other methods of controlling the speeds of water wheels. The heavy floats in water clocks may also be regarded as weights, with the constant-head system as the escapement.

The knowledge that Christians in Spain learned about Muslim water clocks was transferred to Europe. Water clocks in Europe became very elaborate with complications that were often a source of fascination and amusement. There are records of an early medieval water clock where figures of angels would appear every hour, bells would ring, horsemen appeared and a little man, known as a jack, would strike the hour bell with a hammer. This is reminiscent of one of al-Jazari's water clocks.

In a treatise written by Robertas Anglicus in 1271, it is mentioned that the clockmakers - i.e. the makers of water clocks - were trying to solve the problem of the mechanical escapement and had almost reached their objective. The first effective escapement appeared a few years later. This evidence, circumstantial though it is, points strongly to an Islamic influence upon the invention of the mechanical clock.

Astronomical Instruments

The astrolabe was the astronomical instrument par excellence of the Middle Ages; from its Hellenistic origins it was brought to perfection by Muslim scientists and craftsmen. A number of astronomical problems, which otherwise have to be solved by tedious computation, can be solved very quickly by using the astrolabe. It has been established that the first European treatises on the astrolabe were of Arabic inspiration and were written in Latin at the beginning of the eleventh century in the abbey of Ripoll in Catalonia. From this centre the knowledge of the instrument was diffused to the rest of Europe.

were devised in the Muslim world in the later Middle Ages, perhaps the most important of these being equatoria, which were invented in Muslim Spain early in the eleventh century. The objective of the equatorium was the determination of the longitude of any one of the planets at a given time. As with the astrolabe, knowledge of equatoria was diffused into Europe from the Muslim world.

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Al-Jazari and Origin of the Suction Pump and Modern Steam Engine.

Al-Jazari

Ibn Ismail Ibn Al-Razzaz Al-Jazari (1206 AD) was an important Islamic Mechanical Engineer and scholar of the middle ages. He was called Al-Jazari after the area where he was born, Al-Jazira, which is the traditional Arabic name for northern Mesopotamia (in modern-day Syria and Iraq, between the Tigris and the Euphrates). He served the Ortukids a Turkmen dynasty in Diyarbakir as a chief engineer - as did his father before him.

book - roughly translated as "The Book of Knowledge (Or Compendium) of Ingenious Mechanical Devices" illustrated many machines and automata. It is known in Arabic as "Al-Jami Bain Al-Ilm WAl-Amal Al-Nafi Fi Sinat'at Al-Hiyal".

His book showed a deep understanding, and is still analyzed today by the worlds top engineers.

Indeed Muslim Heritage cites this man as the Most Outstanding Mechanical Engineer of his time.

He invented the crankshaft 300 years before the Western Engineers (Francesco di Giorgio Martini and Leonardo Da Vinci)

Prof. Lynn White Jr. writes: "Segmental gears first clearly appear in Al-Jazari, in the West they emerge in Giovanni de Dondi's astronomical clock finished in 1364, and only with the great Sienese engineer Francesco di Giorgio (1501) did they enter the general vocabulary of European machine design".

And he also invented the first mechanical clocks, driven by water and weights. He authored 60 inventions in his book "Al-Jami Bain Al-Ilm WAl-Amal Al-Nafi Fi Sinat'at Al-Hiyal".

Al-Jazari described fifty mechanical devices in six different categories, including water clocks (one of his famous clocks were reconstructed successfully at the london Science Museum in 1976), combination locks, hand washing device, machines for raising water, double acting pumps with suction pipes and the use of a crank shaft in a machine, accurate calibration of orifices, lamination of timber to reduce warping, static balancing of wheels, use of paper models to establish a design, casting of metals in closed mould boxes with green sand, and more. He is also credited for the first recorded designs of a programmable humanoid robot.

Evaluation of Al-Jazari’s work

Al-Jazari’s book deals with a whole range of devices and machines, with a multiplicity of purposes. What they have in common is the considerable degree of engineering skill required for their manufacture, and the use of delicate mechanisms and sensitive control systems. Many of the ideas employed in the construction of ingenious devices were useful in the later development of mechanical technology.

About Al-Jazari’s book Sarton says that "this treatise is the most elaborate of its kind and may be considered the climax of this line of Moslem achievement." Hill concludes also that "until modern times there is no other document, from any cultural area, that provides a comparable wealth of instructions for the design, manufacture and assembly of machines" .

Al-Jazari inherited the knowledge of his predecessors, but he improved on their designs and added devices of his own invention. The merit of his book is that it was the only book to discuss such a large variety of devices and to present them with text and illustrations and dimensions so that a skilled craftsman is able to construct any device on the basis of Al-Jazari's description. In the World of Islam Festival in 1976 it was possible to construct three of Al-Jazari's machines under Hill's supervision. They worked perfectly well. One was a monumental water clock which is exhibited now in the Natuuurmuseum Asten in the Netherlands. [The toy machine shown below, incorporates several principles: the use of water power and a water raising *saqiya* at the same time. An actual machine like this from the thirteenth century, was supplying water from *Nahr Yazid* in Damascus to Ibn Al-'Arabi's mosque until recently, and can be seen until now.]

Many of Al-Jazari's components and techniques were useful in the development of modern mechanical engineering. These include the static balancing of large pulley wheels; calibration of orifices; use of wooden templates; use of paper models in design; lamination of timber to prevent warping; the grinding of the seats and plugs of valves together with emery powder to obtain a watertight fit; casting of brass and copper in closed mold boxes with greensand; use of tipping buckets that discharge their contents automatically; and the use of segmental gears.

Al-Jazari's double acting piston pump is unique (Fig. 2). It is remarkable for three reasons:

1) it incorporates an effective means of converting rotary into reciprocating motion through the crank-connecting-rod mechanism;

2) it makes use of the double-acting principle and

3) it is the first pump known to have had true suction pipes.

of automata, automatic control, robotics and automated musical theaters. His pioneering work is duly acknowledged in most histories.

The inventions of Al-Jazari are a source of inspiration to modern designers such as the use of rolling balls to sound the hours on cymbals and operate automata. This concept is currently used in toys and other devices and their makers had registered patents in their names.

Al-Jazari described a combination lock. There are now in world museums three combination locks that were made in the same period of Al-Jazari. Although they are simpler than the lock of Al-Jazari yet they follow the same principle. Two were made around 597/1200 AD by Muhammad b. Hamid Al-Asturlabi Al-Isfahani and are located in Copenhagen and Boston. The third is in Maastricht. The first combination lock in Europe was described by Buttersworth in 1846 and the wheels of this lock are strikingly similar to the discs of Al-Jazari. All illustrations in Al-Jazari's book are in colour, and among the fifty main drawings are miniatures that are of great artistic merit. This resulted in the disappearance of some of these paintings from the manuscripts and they found their way to the international museums of art or to private collections.

Historians of art are of the opinion that there existed at the court of the Artuqids in Āmid a school of painting that produced narrative paintings of great value Three of the existing Al-Jazari's manuscripts were illustrated by members of this school.

The Origin of the Suction Pump and Modern Steam Engine.

The piston pump of Ctesibius (an engineer from Alexandria, Egypt, 3rd century BC) was described by Philo of Byzantium (2nd century BC) because Ctesibius' book was lost. It was a force pump and was submerged in water; (Fig. 1).

It has the advantage that it will lift water to any height consistent with the pump and the delivery pipe being able to withstand the hydrostatic pressure. But it has significant drawbacks. Firstly, the pumping mechanism is submerged in water; and secondly, if the water-level falls, the cylinder will not fill. The solution to these problems is in the use of a suction pipe on the inlet to the pump. Not only does the suction pipe allow the pump to be set above the water, it will also accommodate changes in the water's level. In theory the suction stage can be about 10 meters (33 feet), the height to which atmospheric pressure will support a column of water, but in practice more than 7.62 meters (25 feet) is almost impossible to realize.

The European piston pump that made its first appearance in the fifteenth-century in the writings of Taccola (c. 1450) and Martini (c. 1475) had a suction pipe incorporated into it. Fig 2. Shows an underdeveloped design with a crude construction.

The cylinder and piston are made from wood that does not sustain pressure, and there is no delivery pipe. Water discharges at the outlet of the pump. Instead of a connecting rod the illustration shows a rope.

There is no proof, however, of a European tradition in piston pumps in the Middle Ages that could have resulted in the development of the suction pump.

The assumption that Taccola (c. 1450) was the first to describe a suction pump is not substantiated. The only explanation for the sudden appearance of the suction pump in the writings of the Renaissance engineers in Europe is that the idea was inherited from Islam whose engineers were familiar with piston pumps for a long time throughout the Middle Ages.

Al-Jazari wrote his book on machines in 1206. Among his water raising machines he described a two cylinder suction piston pump which can be said that it had a direct significance in the development of modern engineering. This pump is driven by a water-wheel, which drives, through a system of gears, an oscillating slot-rod to which the rods of two pistons are attached. The pistons work in horizontally opposed cylinders, each provided with valve-operated suction and delivery pipes. The delivery pipes are joined above the centre of the machine to form a single outlet into the irrigation system. (Fig. 3) and Fig.4)

This pump is remarkable for three reasons:

a) the earliest known use of true suction pipe in a pump,

b) the application of the double-acting principle, and

c) the conversion of rotary to reciprocating motion. It therefore has an important place in the development of the steam engine and .of modern reciprocating pumps.

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The Crank-Connecting Rod System in a Continuously Rotating Machine

Earliest Application in 1206 by Al-Jazari

The crank is the most important single mechanical device after the wheel. It transforms continuous rotary motion into a reciprocating motion. Hand operated cranks were known for centuries, but the incorporation of a crank-connecting rod system in a rotating machine had a different story.

The invention of the crank-connecting rod system is considered by historians of technology to be the most important mechanical device of the early fifteenth century in Europe. Bertrand Gille says that this system was unknown before that date and this had considerably limited the applications of mechanization.

Conrad Keyser (d. c. 1405) described in his book Bellifortis a hand mill operated by the crank and connecting rod system. But Francesco di Giorgio Martini (1439-1502) in his Treatise on architecture illustrated a saw for timber driven by a water wheel in which the crank and connecting rod system was applied for the first time in a continuously rotating machine.(Fig 1).

Leonardo da Vinci (d. 1519) incorporated a crank and rod in his designs. Ramelli also used the crank-connecting rod in a pump in his book of 1588.

In 1206 the crank-connecting rod system was fully developed in two of Al-Jazari’s water raising machines. This is about three centuries prior to Francesco di Giorgio Martini. In Al-Jazari’s fourth machine (Fig 2) the draw bar of an animal rotates a vertical axle. On this axle is a gear wheel meshing at right angles with a second wheel mounted on a horizontal axle which has a crank fitted to it. The free end of the crank enters a connecting-rod under the channel of a flume-beam swape the scoop of which is in a pool.

Al-Jazari’s fourth machine (Fig 2)

As the animal walks in a circle the horizontal axle is turned by the gears and the end of the crank slides in the hinged connecting rod causing it to oscillate around its hinge and thus causing the swape to rise and fall. Fig 3 is a line drawing of the mechanism for this machine.

The other pump in which the crank-connecting rod system was used is Al-Jazari's piston suction pump (his fifth) which we discussed under the title The Origin of the Suction Pump in this project report . We reproduce the illustration of this pump for convenience (Fig 4). We give also the illustration of a similar pump described by Taqi Al-Din in 1551 A.D.

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Water Raising Machines

Throughout history, the supply of water for drinking, domestic, irrigation and industrial purposes has always been a vital consideration in Muslirn countries. The problem has always consisted of finding effective means of raising water from its source.

Early examples of water raising machines include the shaduf (fig 1), saqiya (fig 2) and noria (fig 3). The shaduf was known in ancient times in Egypt and Assyria. It consists of a long beam supported between two pillars by a wooden horizontal bar. A counterweight was attached to the short arm of the beam. A bucket suspended by a rope or a pole was attached

Fig 1. Shaduf

to the long arm of the beam. The bucket was lowered into the water by bearing down on the rope/pole and the counterweight raised the full bucket. The shaduf is still widespread in Egypt.

The saqiya is a animal powered machine. The central mechanism consists of two gears- a large vertical cogwheel and a horizontal lantern pinion-meshing at right angles. The vertical cogwheel is mounted over the source of the water and drives another wheel carrying a chain of earthenware pots ('potgarland') secured by rope. An animAl- donkey, mule or camel- is used to turn the horizontal lantern pinion. As the animal walks in a circular path the potgarland wheel turns. The pots dip into the water, raise it to the surface and discharge it into a tank. The saqiya was known in Roman times. Almost certainly it was in use in Arabia before the advent of Islam. The machine was probably transmitted to Spain from Syria when Muslims introduced their irrigation methods to Spain. The saqiya is still in use in the Muslim world and in the Iberian peninsula and the Balearic islands.

The noria is a water powered machine that is most suitable in areas where there are fast flowing streams whose courses are some distance below the surrounding fields. The wheels are mounted between piers which carry the bearings for the axle. The diameter of the largest wheel is about 20m and there are 120 compartments in the rim. The wheel is turned by the impact of water on paddles mounted on the rim. The compartments dip into the water and are carried to the top where they discharge into a head tank connected to an aqueduct. The noria was already in use in Roman times and was described by Vitruvius in 1 BC. References in the works of Arab geographers show that norias were in use throughout the Muslirn world. Although the machines are now rarely used, some fine examples can still be seen, notably on the River Orontes at Hama in Syria.

At an early stage Muslim engineers were exploring new methods for increasing the effectiveness of water raising machines. Al-Jazari and Taqi Al-Din both described water-raising machines that show an awareness of the need to develop machines with a greater output than these traditional ones.

Al-Jazari was responsible for the design of five machines in the thirteenth century C.E. His first two machines were modifications of the shaduf. The machines used a flume-beam:

Fig 3. The Noria

instead of a pole, an open channel is connected to a scoop, which has its spout elongated into a flume. The scoop dips into the water and when the beam rises the water runs back through the channel and discharges into the irrigation system. The machines were animal powered as in the saqiya.

Al-Jazari's third machine was a development of the saqiya in which water power replaced animal power. Flowing water turned a water wheel which via a system of perpendicular gears caused a chain of pots to raise the water. One such machine was located on the River Yazid in Damascus (13th century) and is thought to have supplied the needs of a nearby hospital.

The fourth machine again used a flume-beamand was animal powered. The beam was moved up and down by an intricate mechanism involving gears and a crank. This is the first known instance of the use of a crank as part of a machine- the earliest appearance in Europe of a crank as part of a machine occured in the fifteenth century C.E.

Al-Jazari's fifth machine, a water-driven pump was a more radical device. A water wheel turned a vertical cog wheel which in turn turned a horizontal wheel. The latter caused two opposing copper pistons to oscillate. The cylinders of the pistons were connected to suction and delivery pipes which were guarded by one-way clack valves (i.e. hinged at one end). The suction pipes drew water from a water sump down below and the delivery pipes discharged the water into the supply system about 12m above the installation. This pump is an early example of the double-acting principle (while one piston sucks the other

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Irrigation and Water Supply

With the spread of the Islamic Empire westward, agricultural and irrigation methods and techniques were introduced into the western regions of Islam. The rulers of Al-Andalus and many of their followers were of Syrian origin, and the climate, terrain and hydraulic conditions in parts of southern Spain resemble those of Syria. It is hardly surprising, therefore, that the irrigation methods - technical and administrative - in Valencia closely resemble the methods applied in the Ghuta of Damascus.[2]

There is a unanimous opinion among historians that the present Spanish irrigation systems of Valencia and Andalusia are of Muslim origin. In 1960 a celebration was held in Valencia commemorating the ‘Millennium of the Waters’. It expressed public recognition of the establishment of the irrigation system, and specifically of the Tribunal of Waters during the reign of 'Abd Al-Rahman III'.

The irrigation system that had been instituted in the days of the caliphs in Valencia was perpetuated and confirmed under the succeeding dynasties, until, when the Christian conquerors appeared in the thirteenth century, it recommended itself for adoption, backed by the experienced benefits of several centuries. The Arabic names used in the irrigation systems give distinct proofs of the Moorish origin of the irrigation systems in eastern Spain.

There is some difference between eastern Spain (Valencia and Murcia) and the kingdom of Granada. The chief object of the Granada water supply system was not the irrigation of crops only but the distribution of water to the fountains and baths of the capital. In Granada the system is still "to an exceptional degree" the same as it was in the time of the Arabs, and we find undisturbed the institutions practiced by the Arabs themselves.

The Arabic systems in irrigations were diffused from Al-Andalus to Christian Spain. This accounts for the Aragonese traditions of irrigation.

These systems of irrigation had migrated from Spain to America where we find them still practiced in San Antonio in Texas. The story begins properly in the Canary Islands where in the late fifteenth century; settlers from Spain introduced Islamic institutions of water distribution. They brought with them to the American southwest both the technology and institutional framework for irrigation and the distribution of water.

The Qanat

The qanat system was an efficient method for irrigation and water supply. It originated in pre-Islamic Iran. The qanat technology spread westward to North Africa, Spain, and Sicily. The Andalusi agronomical writers provide practical advice on well-digging and qanat construction.

From Spain the qanat technology was transferred to the New World and qanats have been found in Mexico, Peru, and Chile. In the 1970s a qanat system 2.3 kilometers long was located in the La Venta area, just 10 km northwest of Guadalajara, Mexico.

In Palermo, Italy, a qanat system from the Arab days was used to bring fresh water to the city and to irrigate its beautiful gardens. There are current plans to revive and reconstruct the Arabic qanat and utilize it to solve the acute needs of the modern city of Palermo for potable water. The project in hand is of great historical, archaeological, geological and hydro-geological importance. It is already of great interest for tourists.

Dams

There are many Muslim dams in Spain, a large number of which were built during the tenth century AD, the golden age of Umayyad power in the peninsula. In this period, for example, many small dams, or azuds, were built on the 150-mile-long River Turia, which flows into the Mediterranean at Valencia. (In passing it is important to note the Spanish word azud, from Arabic Al-sadd, one of many modern irrigation terms taken directly from Arabic and certain proof of Muslim influence on Spanish technology.) Eight of these dams are spread over six miles of river in Valencia, and serve the local irrigation system. Some of the canals carry water much further, particularly to the Valencian rice fields. These, of course, were established by the Muslims, and continue to be one of the most important rice-producing centres in Europe. Because of their safe design and method of construction, and because they were provided with deep and very firm foundations, the Turia dams have been able to survive the dangerous flood conditions for 1000 years.

Power from Water and Wind

The Muslim geographers and travelers leave us in no doubt as to the importance of corn-milling in the Muslim world. This importance is reflected by the widespread occurrence of mills from Iran to the Iberian Peninsula. Arab geographers were rating streams at so much 'mill-power'. Large urban communities were provided with flour by factory milling installations.

The ship-mill was one of the methods used to increase the output of mills, taking advantage of the faster current in midstream and avoiding the problems caused by the lowering of the water level in the dry season. Another method was to fix the water-wheels to the piers of bridges in order to utilize the increased flow caused by the partial damming of the river. Dams were also constructed to provide additional power for mills (and water-raising machines) In the twelfth century Al-Idrisi described the dam at Cordoba in Spain, in which there were three mill houses each containing four mills. Until quite recently its three mill houses still functioned.

Evidence of the Muslims' eagerness to harness every available source of water power is provided by their use of tidal mills in the tenth century in the Basra area where there were mills that were operated by the ebb-tide. Tidal mills did not appear in Europe until about a century after this.

Water power was also used in Islam for other industrial purposes. In the year 751 the industry of paper-making was established in the city of Samarqand. The paper was made from linen, flax or hemp rags. Soon afterwards paper mills on the pattern of those in Samarqand were erected in Baghdad and spread until they reached Muslim Spain. The raw materials in these mills were prepared by pounding them with water-powered trip-hammers. Writing about the year 1044, Al-Biruni tells us that gold ores were pulverized by this method "as is the case in Samarqand with the pounding of flax for paper". Water power was also used in the Muslim world for fulling cloth, sawing timber and processing sugarcane. It is yet to be established to what extent industrial milling in Europe was influenced by Muslim practices. A likely area of transfer is the Iberian Peninsula, where the Christians took over, in working order, many Muslim installations, including the paper mills at Jativa.

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Flywheel Effect for a Saqiya From Kitab Al-Filaha of Ibn Bassal (1038-1075)

A flywheel is attached to a rotating shaft so as to smooth out delivery of power from a driving device to a driven machine. The inertia of the flywheel opposes and moderates fluctuations in the speed of the driver and stores the excess energy for intermittent use. In other words it smoothes out the flow of power. The flywheel was utilized very early in history in potters' wheels and in ancient Egyptian drilling devises. It started to be used in machinery in Europe only in the sixteenth century.

This Brief Note is about an ingenious devise that was described by Ibn Bassal in the eleventh century for utilizing the flywheel effect in a saqiya. A weight is placed behind the animal on the drawbar which is rotating around the vertical shaft of the saqiya. The resulting extra inertia that is stored in the weight is required for the proper operation of the saqiya. Using a weight to produce a flywheel-effect, the operation will be smoother and the load on the animal will be minimized. The flywheel weight allows the peaks and valleys of the torque to be reduced.

The following is what Ibn Bassal says. The Arabic text is given at the end of this Note.

"Chapter: if the well is deep so that its rope is more than twenty fathoms (qama) [and] if the extraction of water becomes weak and the weight of the saqiya's rope becomes heavy for the animal then the ingenuous device for making the load light and easy is to install the saqiya at the mouth of the well in a similar manner to other saqiyas. Then you consider the upright shaft that carries the pinion and you cut off the upper part leaving about one shibr (hand span) in length. Then drill a hole in the middle of the remaining upright shaft. Insert the drawbar into this hole. Drill two holes along the drawbar with a space between them sufficient for accommodating the animal with its rump. The draw robes that are attached to the animal pass through these two holes. Between the two holes on the draw bar, through which pass the draw ropes, place a supporting frame or bed. On this supporting frame or bed place a weight of stones equal to four or five arba`s (Sp. Arrobas). The weight will be located opposite the rump of the animal, not hanging down but resting on the bed. With this arrangement it will become easy for the animal to draw water out from the deep well even if its depth reached one hundred fathoms. The animal will not find any burden or heaviness caused by the weight opposite to its rump, and the slightest effort will cause the saniya (saqiya) to move.

If one is afraid that the drawbar will bend or something else because of its great length we will drill in the remaining part of the upright shaft two holes, one of them above the drawbar and other underneath it, and will put in them two rods of a combined thickness equal to that of the drawbar, these rods will be securely attached to the drawbar and rounded at their ends to fit on it. The ends will be securely held and tightened together with the drawbar at its middle by an iron ring. if the drawbar measured thirty hand spans in length, the two rods will be about fifteen hand spans long each, and if the drawbar will be smaller, then both rods are decreased in length in a proportionate way; and by this construction the drawbar is strengthened without fear of its bending."

Muhammad b. Ibrahim Ibn Bassal, lived in Toledo. He devoted himself exclusively to agronomy. He also was in the service of Al-Ma'mun sultan of Toledo (1038-1075), for whom he wrote a lengthy treatise on agronomy (Diwan Al-filaha); this work was subsequently abridged into one volume with sixteen chapters. This work, which was translated into Castilian in the Middle Ages, was published in 1955 together with the Arabic text, (see below). The treatise by Ibn Bassal is singular in that it contains no reference to earlier agronomists; it appears to be based exclusively on the personal experiences of the author, who is revealed as the most original and objective of all the Hispano-Arabic specialists.

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[7] Shibr or span is the distance from the end of the thumb to the end of the little finger of a spread hand; In English unit of length a span is equal to 9 inches (22.9 centimeters).

[8] Rub` pl. araba, a measure of weight. Al-rub` (Spanish arroba) equals 25 Spanish pounds or 11.502 kg. Four arrobas equal 46 kg, and five equal 57.51 kg.

Taqi Al-Din and the First Steam Turbine

1551 A.D.

The traditional histories of technology ascribe to Giovanni Branca the first description of a steam turbine in 1629[1]. In 1648 John Wilkins in his book Mathematical Magic described a steam turbine for rotating a spit

It is important to know that Taqi Al-Din had described in his book Al-Turuq Al-saniyya fi Al-alat Al-ruhaniyya (The Sublime Methods of Spiritual Machines) which he completed in 959/1551, a steam turbine as a prime mover for rotating a spit. Thus he preceded Branca by 78 years and Wilkins by 97 years. Here is what Taqi Al-Din says:

"Part Six: Making a spit which carries meat over fire so that it will rotate by itself without the power of an animal. This was made by people in several ways, and one of these is to have at the end of the spit a wheel with vanes, and opposite the wheel place a hollow pitcher made of copper with a closed head and full of water. Let the nozzle of the pitcher be opposite the vanes of the wheel. Kindle fire under the pitcher and steam will issue from its nozzle in a restricted form and it will turn the vane wheel. When the pitcher becomes empty of water bring close to it cold water in a basin and let the nozzle of the pitcher dip into the cold water. The heat will cause all the water in the basin to be attracted into the pitcher and the [the steam] will start rotating the vane wheel again."

Extract from

Al-Turuq Al-saniyya fi Al-alat Al-ruhaniyya (The Sublime Methods of Spiritual Machines). See Ahmad Y. Al-Hassan, Taqi Al-Din and Arabic Mechanical Engineering, Instiute for the History of Arabic Science, Aleppo University, 1976, pp. 34-35.

The Origin of Damascus Steel In Arabic Sources

http://by18fd.bay18.hotmail.msn.com/l [1]HYPERLINK /l [1]

AI-Kindi on Sources and Centers of Production

Among the extant works of Abu Yusuf b. lshaq Al-Kindi (fI. 850), "the philosopher of the Arabs", is "A Treatise (Addressed) to some of His Brethren Concerning Swords The treatise contains much useful technological information. But we shall be content in this paper to give Al-Kindi's classification of the various kinds of iron and steel from which swords were being made. The passages below have been excerpted from this treatise.HYPERLINK \l "_

Natural and not-natural iron:

"Learn that iron from which swords are forged is divided into two primary or main divisions: natural (as mined) and not-natural (i. e. manufactured). Natural iron is divided into two divisions: shaburqan and it is the male, hard iron which can be heat-treated by its nature, and narmahin (narm-ahin), which is the female soft iron which cannot be heat-treated by its nature. [Swords] can be forged from either of these two kinds or from both combined. Thus, aIl kinds of swords made of natural iron fall into three kinds: shaburqani, narmahani, and those made of a combination of both."

Not-natural or manufactured iron or steel:

"Iron which is not natural (i.e. manufactured) is steel or fuladh. 1t means the refined or purified المصفّى. It is made of natural iron by adding to it while smelting sorne (ingredients) for purifying it, and for decreasing its softness, until it becomes strong, flexible, susceptible to heat treatment, and until its firind appears."

Three main qualities of steel:

"This steel is divided into three divisions: the antiquethe modem , and the non-antique, non-modern. Swords may be forged from all these steels. Thus, there are three kinds of swords: the antique, the modern, and the non-antique, non-modern."

"Antique" means top quality steel:

" Antique is not related to time (or age) but it indicates the noble or the generous qualities, as when it is said "an antique horse" meaning a noble horse (of good breed). That (sword) which has the noble qualities is "antique", no matter in which age it was forged. At the extreme end of the "antique" is its opposite in meaning, I mean that (sword) which is deprived of the qualities of the "antique". That is why it was given an opposite name, i. e. modern, even if was forged before the time of `Ad. Those (swords) which have sorne qualities of the "antique", but which are deprived of sorne of its qualities, are the swords which exhibit sorne of the qualities of the "modern". Therefore, these swords are given a name in the middle between both, and they are classified as non-antique, non-modem even if they are forged in ancient or modern times. Sword- makers called some of these swords "non-antique", and called some others "non-modern".

Three kinds of "antique" or quality swords:

"The antique are divided into three kinds. The first and best in quality of all is the Yemenite; the second is the Qal`i and the third is the Indian."

Swords forged from imported steel:

Some swords were called non-native غير مولّد. They were forged from imported steel. Some Khurasani swords for example were forged from steel imported from Sarandib; and this is the case in several other cities.

Swords forged from local iron:

"As for those native swords مولّدة, they fall into five kinds. Of these are the Khurasani, the iron which is produced and forged in Khurasan; the Basriyya, the iron of which is produced and forged at Basra; the Damascene, the iron of which is produced and forged at Damascus; the Egyptian, which is forged in Egypt. Swords in this category may be forged in other places like those of Baghdad, of Kufa, and a few other places, but are not attributed to such places because of their scarcity. These are all the types of swords which are made from manufactured iron, I mean from steel."

Al-Biruni on Damascus Crucible Steel

The next passage is from Kitab Al-Jamahir fi ma`rifat Al-jawahir (A Compendium of Mineralogy(written by the celebrated savant, Abu Al-Rayhan Al-Biruni (973 -1048). Two main manuscripts were consulted. The first is Ms. Topkapi 2047 from Istanbul, and the other is Ms. Casiri 905 from the Escorial. Similarly, the book printed in Hyderabad was also consulted (Kitab Al-Jamahir, edited by E. Krenkow, Hyderabad, 1936/37). Al-Biruni says:

"Mazyad b.`Ali, the Damascene blacksmith, wrote a book describing swords that were specified in Al-Kindi's treatise. He commenced by dealing with the steel composition and the construction of the furnace (kur) as weIl as with the construction and design of crucibles, the description of (the varieties) of clay, and how to distinguish between them. Then he instructed that in each crucible five ratls of horseshoes and their nails should be placed, which are made of narmahin, as well as a weight of ten dirhams each of rusukhtaj , golden marcasite stone and brittle magnesia. The crucibles are plastered with clay and placed inside the furnace (kur). They are filled with charcoal and they (the crucibles) are blown upon with rumi bellows. each having two operators, until it (the iron) melts and whirls. Bundles are added containing ihlilaj (myrobalan), pomegranate rinds, salt (used in) dough, and oyster shells, lit. pearl shells, in equal portions, and crushed, each bundle weighing forty dirhams. One (bundle) is thrown into each crucible; then it (the crucible) is blown upon violently for an hour. Next, they (the crucibles) are left to cool, and the eggs are taken from the crucibles."

Al-Jildaki (commenting on Jabir ibn Hayyan) Discusses Pig Iron and Cast Steel

lt was found that Ms. no. 4121 of the Chester Beatty Library, contains a part of Kitab Al-Hadid (The Book of lron) of Jabir ibn Hayyan, that is given in the course of a commentary by Al-Jildaki (fi. c. 1339 -42). The following text from this Ms. is of great significance for the history of metallurgy:

"Chapter: Learn, brother, that it is your comrades who found (from founding, melt metal iron in foundries (especially) made for that purpose after they have extracted it (the ore) from its mine as yellow earth intermingled with barely visible veins of iron. They place it in founding furnaces designed for smelting it. They install powerful bellows on all sides of them after having kneaded (يلْتّون) a little oil and alkali into the ore. Then fire is applied to it (the ore), together with cinders and wood. They blow upon it until it is molten, and its entire substance is rid of that earth. Next, they cause it to drop through holes like (those of) strainers, (made in) the furnaces so that the molten iron is separated, and is made into bars from that soil. Then they transport it to far lands and countries. People use it for making utilitarian things of which they have need.

As for the steel workers, they take the iron bars and put them into founding-ovens which they have, suited to their objectives, in the steel works. They install firing equipment into them (the ovens) and blow fire upon it (the iron) for a long while until it becomes like gurgling water. They nourish it with glass, oil, and alkali until light appears from it in the fire and it is purified of much of its blackness by intensive founding, night and day. They keep watching while it whirls for indications until they are sure of its suitability, and its lamp emits light; Thereupon, they pour it out through channels so that it comes out like running water. Then, they allow it to solidify in the shape of bars or in holes made of clay fashioned like large crucibles. They take out of them refined steel in the shape of ostrich eggs, and they make swords from it and helmets, lance heads, and all tools." (see Arabic text below)

From these two descriptions it seems safe to state that the first process describes the production of pig iron (or cast iron), and that the second one describes the production of cast steel from pig iron.

Iron Foundries in Damascus in the Twelfth and Thirteenth Centuries

Reference to iron foundries in Damascus in medieval times can be found in Arabic literature. Thus, in the book Subh Al-a`sha (Cairo: Ministry of Culture) by Al-Qalqashandi (d. 1418), when discussing government departments in Damascus during the Ayyubid dynasty (1171-1250), the following statement occurs (vol. 4, p. 188):

"Of these are several small military departments شدود such as the department of foundries شدّ المسابك for iron, copper, glass, and others."

Then, (on p. 190), Al-Qalqashandi speaks about departments of the civil service in Damascus and says:

"Of these is the civil department of foundries نظر المسابك and the executive in charge of this department is the counterpart of the officer in charge of the military department of foundries شدّ المسابك who was mentioned above when dealing with military officers (men of the sword). "

The History of Damascus City (Damascus: Arab Academy of Science,1954) by Abu Al-Qasim `Ali ibn Al-Hasan, known as Ibn `Asakir (d.1177), mentions (vol. 2, p. 58) the sites of iron foundries in Damascus.

6. Distinction between Indian and Damascus Steels in Arabic Literature

Zayn Al-Din Al-Dimashqi Al-Jawbari(d.1232) wrote his book A Selective Book on Revealing Secrets printed Damascus, 1302 H) as a guidebook on how to discover cheating methods adopted by various trades and crafts. Chapter eight is on "revealing secrets of manufacturers of arms ". The following passage occurs (p. 61):

"They have a prescription for a (good) cutting sword: Indian steel or Damascus steel is taken and a sword is made of these steels which is strong (thick) in the middle and thin at the edges, with evenness such that no place is stronger than the other. Then, if it is heat-treated with the above-mentioned water, nothing can oppose it."

The passage below shows that the term "Damascus steel" was current during the fourteenth century. The quotation is from a manual on quality control by Dia' Al-Din Muhammad Al-Qurashi, known as Ibn Al- Uhkuwwa, (d. 1329). The book is Ma`alim Al-qurba fi ahkam a-hisba (ed. Reuben Levy, Cambridge, 1938; repr. Baghdad, Muthanna), p. 224:

"An honest and trustworthy (individual) from among them (the artificers) is chosen (as inspector). He prevents (them) from mixing steel needles with (those made of) armahan (soft iron, narmahin) for, when sharpened, they may be taken for those made from Damascus steel. Therefore each quality should be separate from the other, and he should take an oath from the artisans to follow these regulations. "

The Firind or the "Damask" Pattern on Blades

All Islamic swords that were made from "Damascus steel" or from steels of similar quality showed the peculiar pattern that was referred to in Arabic literature as firind or "jawhar". The processes of producing steels in crucibles were practiced in Islamic lands mostly from native iron ores as we have shown above.

From Al-Kindï's treatise, we learn that the "Damask" pattern or Firind ا or jawhar ا is found in all manufactured steels. According to him, swords made from natural steels (non-manufactured, Shaburqan) have no pattern or "firind". When speaking about the firind of swords made from natural steel, Al-Kindï states:

"These swords show no firind when treated with tarh or when treated otherwise, and aIl their iron is one colour."

On the other band, aIl swords made from manufactured steel show the "firind" in varions degrees. Al-Kindi describes the "firind" or pattern of all types of manufactured steels and of swords produced in various localities in Islamic lands, and of Indian steel.

Al-Biruni in his above mentioned book (Al-jamahir) gives a very interesting interpretation of the cause behind the formation of the firind or pattern in steels. It is due, in his opinion, to the incomplete mixing of two components of steel in the crucible: soft iron (narmahin) and its water (dus):

"As to (iron) which is made from narmahin and its water which flows before it when it gets rid (of its impurities), it is caIled fuladh (steel).

Then he states:

"Fuladh (steel) in its composition is of two types. Either all that is in the crucible, narmahin and its water, is melted equally so that they become united in the mixing operation and no component can be differentiated or seen independently, and such steel is suitable for files and similar tools (and one may imagine that shaburqan is of such type and of a natural quality suited to hardening); or the degree of melting of the contents of the crucible varies, and thus the intermixing between both components is not complete, and the two components are shifted and thus each of their two colours (components) can be seen by the naked eye and it is called firind." AI-Biruni gives his definition of the two components of steel (which give rise to the firind) at the very beginning of the chapter on iron and he states:

"Narmahin is divided ...into two types. One is (narmahin) itself, and the other is its water which flows from it when it is melted and extracted from stones, and it is called dus دوص, in Persian it is called astah, and in the area of Zabilstan, ru رو, because of its speed of flow and because it overtakes iron when it is flowing. It is solid, white, and tends to be silvery."

Al-Biruni’s interpretation of the cause of the firind or pattern in Damascus steel is reminiscent of the modern interpretation of modern historians of metallurgy who were studying the secret of Damascus steel for the last two centuries.

Gunpowder Composition for Rockets and Cannon, In Thirteenth and Fourteenth Centuries

A Gap in the history of gunpowder and cannon

In some documented histories of warfare and weapons in the Middle Ages and the Renaissance there is a noticeable gap in the history of gunpowder and cannon in the thirteenth and fourteenth centuries. Some Authors jump from China in the Far East to Europe in the far west with the slightest reference or no reference at all to the Arabic and Islamic lands that spanned the whole distance between east and west. In the thirteenth century, technology could hardly have been transferred between the two extremities of the old world unless it passed through the Arabic and Islamic medium and subjected to more developments.

It is not our purpose in this paper to review the history of gunpowder and cannon in China and Europe. We shall revisit some Arabic sources that were known and repeatedly discussed since the middle of the nineteenth century,., and shall discuss briefly the development of cannon in the thirteenth and fourteenth centuries in the Mamluk Kingdom and in Muslim Spain:

Development of cannon in Al-Andalus and Al-Maghrib in the 13th and 14th centuries

We have no extant Islamic military treatises left to us from Al-Andalus and Al-Maghrib regarding gunpowder. But since this symposium is taking place in Granada, the seat of the last Moorish kingdom in Al-Andalus, it befits us to give a brief account of the history of cannon in this area.

Reports about the use of cannon by the Arabs in Spain are given in the works of Spanish and Arab historians who were closer to the times of the events or even have witnessed them. When they wrote their accounts they did not have the same thinking that triggered the debate among historians of gunpowder and firearms of the 19th and the first decades of the 20th centuries. The question about the first nation to formulate propulsive gunpowder or to use cannon was irrelevant to them. In the last three decades of recent history some scholars adopted a more balanced attitude and started to free themselves from the euro centric way of looking at historical sources. In this brief survey, we shall present the primary reports about the main events without trying to confuse the reader with the disputations of the past two centuries.

Most of the argument arose when some historians tried to interpret the Arabic word naft to denote naphtha or a mixture of incendiary ingredients containing naphtha. A study of the titles of treatises dealing with gunpowder composition given in this article will make it clear that naft denoted in fact gunpowder. The term naft was used originally for military fires of any composition, and as soon as the new mixture of saltpeter-sulphur-charcoal was known, the word naft was applied to it. So the treatise of `Iyarat Al-naft mentioned above means Formulations of Gunpowder as we have seen.

In the Vocabulista (a Latin-Spanish Arabic vocabulary compiled in the region of Valencia, in the 13th century), one finds the word naft opposite Ignis and Ignem excutere. In the later historical accounts this word denoted gunpowder. In Al-Andalus in the course of the second half of the 15th century, gunpowder became barud, and saltpetre became milh Al-barud. Naft (pl. anfat) then denoted cannon, and naffat denoted gunner.

When we discuss the development of gunpowder and cannon in Al-Andalus and Al-Maghrib countries, we must take into account their parallel development in the Arab east namely in the Mamluk Kingdom.

Another factor that is relevant to our study is the fact that potassium nitrates were abundant in Muslim Spain, and it was the only country in Europe having these natural deposits.[44] Watson says in his Chemical Essays: "The lands of Spain, says the author of its Natural History, if properly managed, would supply all Europe with saltpetre to the end of the world."

The Arabs are reported to have used rockets on the Iberian Peninsula in 1249; and in 1288 rockets attacked Valencia. This report needs to be investigated further in order to determine the sources of information.

Peter, Bishop of Leon, reported the use of cannon by the Arabs while defending Seville in 646 AH/ 1248 AD. Ferdinand III harassed Seville increasingly and kept the town under siege for 17 months until it surrendered. At this same time, in the Mamluk Kingdom, gunpowder was already in use in warfare during the Crusades, and if the devices used in Seville were not cannon, then they were most probably projectiles utilizing gunpowder similar to those used by the Mamluks in the battle of Al-Mansura in 1250 against Louis IX.

In 660 / 1262, King Alfonso X of Castile succeeded in conquering the city of Niebla. The siege was not easy either for the besiegers or for the Muslim inhabitants due to the strength of the town’s defences, so the siege lasted nine months and a half. It is reported that Almohads in defending the city used machines that resembled cannon, which projected stones and fire accompanied by thundering noises. Some Spanish histories consider that this was the first time that gunpowder had been used in warfare in Spain.

Ibn Khaldun (8th/14th century) says that the Marinid Sultan Abu Yusuf Ya`qub, when besieging the town of Sijilmasa in 672-3/1274:

"Brought into action against this town mangonels (majaniq) and ballistas (`arradat), as well as a naft engine (hindam Al-naft i.e. gunpowder cannon) which discharged small iron balls (hasa Al-hadid). These balls are ejected from a chamber (khizana) placed in front of a kindling fire of gunpowder. This happens by a strange property which attributes all actions to the power of the Creator."

This precise information about the use of cannon came from a great historian. However, western historians of firearms in the nineteenth and the first part of the twentieth centuries questioned the report of Ibn Kaldun. Historians in those days were bound by certain fixed historical dates for gunpowder and cannon that could not be changed even if they go to the extreme of discrediting a historian of the calibre of Ibn Khaldun. We have seen above that portable cannon were used by the Mamluks in 1260 in the battle of `Ayn Jalut. Indeed, we would advance the view that in the Maghrib and Al-Andalus, where petroleum was not available whereas potassium nitrate was known to be abundant, cannon may have developed into a siege engine somewhat earlier than in the Islamic East, and that the appearance of cannon at Sijilmasa as described by Ibn Khaldun was a natural development the veracity of which need not be doubted.

In the fourteenth century, the historic accounts regarding the use of cannon by the Moorish kings of Granada, in defensive as well as offensive operations had caused considerable debate among western historians in the nineteenth and the first decades of the twentieth centuries. After reviewing the position of some military historians in Europe, Ada Bruhn de Hoffmeyer in her carefully focused survey, Arms and Amour in Spain, concludes that:

"The old theories about the Arabs and the Moors and their importance in regard to gunpowder and early artillery in the 14th century cannot be rejected---on the contrary! Alchemy and chemical experiments flourished among the Arabs in the Mediterranean world not least in Moslem Andalusia, and Saracen scientists and technicians were working at various courts of occidental Europe."

"The general opinion no doubt must be that gunpowder artillery was introduced rather early to Spain through the Arabs via the Moors of Maroc and from them to Moslem Andalusia. From the Hispano-Moors Christian Spain learned about gunpowder artillery. The routes probably passed via the Granadine kingdom, which at that time had very close contacts with the sultan of Maroc in Fez, from which place Granada got military help against the Christians. Italy is represented with the Genoese navy supporting Granadines and Moroccanes."

The facts depend upon the correct translation of certain words from Arabic manuscripts. Hoffmeyer refers to the work of Kohler when she says:

"It is not impossible that G. Kohler in his work: Die Entwicklung des Kriegswesens und der Kriegsfiihrung, Breslau 1887, was right in his suppositions that the Arabs rather early introduced not only gunpowder but even fire-arms to Spain, from whence they passed to Italy (coincidence with the documentation from Florence) and from Spain and Italy to France and Germany. (The routes from Hispano- Moorish Andalusia, passing through Murcia, the Levantine coasts of Spain, Aragon to Italy is nothing strange in the 14th century, when the Mediterranean was a «Mar Aragones».) "

The main incidents we are concerned with in the following account had taken place during the tenure of Sultan Abu Al-Walid Isma`il ibn Nasr (713 AH/ 1314 AD-725 AH/1325 AD), the Nasrid king of Granada who waged a number of successful campaigns between the years 1324 and 1325. In 724/1324 he besieged the fort city of Huescar using cannon in his siege, of which Lisan Al-Din ibn Al-Khatib (1313-1374) who was a youth at the time, and who became later a minister in Granada, relates:

"He headed towards the enemy territory and challenged the fort of Huescar that stands as a bone in the throat of Baza, which he besieged and attacked. He struck the arch of the invincible tower with a red-hot iron ball bombarded by the great engine that operates by naft (gunpowder). "

To celebrate the occasion, the scientist and poet, Abu Zakariyya Yahya ibn Hudhayl whom Ibn Al-Khatib highly praised, being his teacher, had composed a poem complementing the sultan for the conquest of Huescar:

"They thought that the thunder and the lightning had come down from the skies; whereas the thunder and lightning are all around them being created by man.

These are things of wondrous shapes, sent high by Hermes and engineered to demolish mountains when they hit.

Yes, it is this world that always shows you miracles, since nature's innate powers are destined to appear "

Based on the reports of these eyewitnesses McJoynt concludes that:

"Granada must have been in the forefront of technical innovation in the world at this time. The new weapon was a success, for Huescar hastened to surrender".

Lomax concludes also that "The capture of Huescar had seen the first use of gunpowder and cannon in European warfare."

After the conquest of Huescar, Sultan Isma`il waged a number of campaigns in which he captured a number of cities and forts including Baza and Martos in which he used cannon also.

In 732 /1331 Sultan Muhammad IV laid siege to the city of Alicante, of which the Spanish historian Zurita (1512-1580) maintains that "when the Moorish king of Granada besieged Alicante he used a new machine that caused great terror. It threw iron balls with fire." [58] Hoffmeyer finds the report of Muslim gunpowder weapons at Alicante to be "difficult to deny", given obvious awareness of such weapons at the time.

In a confrontation, known as the battle of Tarifa or the battle of Rio Salado in 1340, the Arabs lost heavily to the Castillian armies and their allies. The Spanish historian Conde relates that in the battle of Tarifa the Arabs had employed machines of thunder that launched iron balls propelled by nafta, causing extensive damage to the towers and the fortifications of the city.

However, the main objective of the Spaniards was to occupy and hold on to the strategic port city of Algeciras (Al-Jazira), situated next to the straight of Gibraltar. They had engaged the aid of their allies in Europe in a crusade against the Arabs, to which France and England were among respondents by sending army contingents. The siege of the city lasted twenty months, from 1342 to 1344, during which time the Arabs defended the city courageously, using cannon profusely and engaging the enemy in daring encounters.

The Spanish historian Juan de Mariana (1536-1623) described the use of gunpowder and cannons during the capture of Algeciras. He states:

"The besieged did great harm among the Christians with iron bullets they shot. This is the first time we find any mention of gunpowder and ball in our histories."

De Mariana also relates that the English Earl of Derby and Earl of Salisbury had both participated in this siege. Richard Watson thinks that the two earls had conceivably transferred the knowledge about cannon and gunpowder and their use as effective firearms to England, and that the English adopted this new weapon and used it in the battle of Crecy in 1346. Furthermore, Prescott in his book Ferdinand and Isabella emphasizes that the Spaniards had adopted their knowledge of gunpowder from the Arabs of Granada who were familiar with its utilization for a considerable time before their encounter with the Spanish in this siege. Ada Bruhn Hoffmeyer finds it "fully trustworthy" that King Alfonso XI of Castile and the Muslims used "gunpowder as propulsor for projectiles" at Algeciras in 1342.

The use of gunpowder and cannon spread quickly in Spain. The Spanish kings at the initial stages enlisted the help of Moorish experts. Hoffmeyer says:

"The first artillery-masters on the Peninsula probably were Moors in Christian service. The king of Navarra had a Moor in his service in 1367 as «maestro de las guarniciones de artilleria. The Morisques of Tudela at that time had fame for their capacity in reparaciones de artilleria."

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6. Ibn Khaldun. P.188
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End