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Chapter

10

Chemical Knowledge and Practices in Ancient and Medieval India

Saptarshi Biswas

Abstract: Chemical process is a phenomenon that came before the formation of the Earth and increased exponentially with civilization. India is such a country where civilization started from the Indus Valley era. Science and technology are the key factors to developing a country, where chemistry is one of the accelerating factors. In ancient and medieval times, many chemical practices were used in India that many of us can't even imagine, like the mining and metallurgical industry, fermentation, wootz, etc. In this chapter, we try to enlighten such well-known and unknown chemical knowledge that might be interesting to the common people.

Keywords: Ancient Indian chemistry, Metallurgy, Mining, Fermentation, Wootz

Introduction:

At the time of the ancient and medieval ages, Hindus were doing sciences in many categories, *e.g.*, mechanical, physical, chemical, mathematical, and medical sciences. Among them, chemical science has dealt with various applications towards health-related problems. In *Susruta-Samhita*[1] *Rasayana-tantra* (chemistry) is defined as the science "for the prolongation of human life and the invigoration of memory and the vital human organs. It deals with the recipes that enable a man to retain his manhood or youthful vigor up to a good old age, which generally serve to make the human system immune to disease and decay." Again in the *Rgveda*[2] and *Atharvaveda,* the elixir of life is called Soma – which was synthesized with the knowledge of chemistry. Soma is a liquid drink to revive somebody and to delay the aging process or anti-aging. The *Atharvaveda*[3] advises: "Invest this Soma for long life; invest him for great hearing power." Chemistry, a rejuvenation treatment in Ayurveda, was used to enhance the life span. This treatment helps to restock the liquid (*rasa*) and additional element (*dhatu*) to the body. The resolution of chemistry, as described by Caraka, includes the attainment of excellent memory, long life, and freedom from disease; strong body powers, good complexion; a healthy glow; and a powerful voice.[4] Caraka and Susruta describe the processes of sublimation, distillation, and calcination in the chemical purification of metals.[5] Additionally, Caraka mentions the use of iron, copper, gold, mercury, and lead in drugs and advises several ointments are synthesized from sulfur, iron sulfate, and copper sulfate used to treat many skin diseases.[6] Medicinal treatments also involved the use of oxides of iron, copper, zinc, tin, and lead. The Indian Peninsula is native to these metals. Caraka prepared drugs by reacting very fine sheets of gold, iron, and silver with alkali and salts.[6] The Upanisad mentions alloys such as gold with silver, gold with salt (borax), silver with tin, and lead with copper.[7]

Dr. Saptarshi Biswas
Department of Chemistry, Katwa College, Katwa 713130, Purba Bardhaman, West Bengal, India
E-mail: heysaptarshi@gmail.com

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Venoms and antidotes were developed, frequently mentioned in the Ramayana, Mahabharata, and Kautilya's Arthashastra as *astra* (chemical weapons) used in warfare. Kautilya described a deadly method of poison gas, stating: "The smoke caused by burning the Powder of *satakardama*, uchchidihga, karavira, katutumbi, and fish, together with the chaff of the grains of *madana* and *kodrave*, or with the chaff of the seeds of hastikarna (castor oil tree) and palasa destroys animal life as far as it is carried off by the wind."[8] Complicated procedures were used to invent several deadly poisons: "The smoke caused by burning the powder made of the mixture of the dung and urine of pigeons, frogs, flesh-eating animals, elephants, men, and boars, the chaff and powder of barley mixed with kasisa (green sulphate of iron), rice, the seeds of cotton, kutaja, and kosataki, cow's urine, the root of bhandi, the powder of nimba sigru, phanirjaka (a kind of basil or tulsi plant), *kshibapiluka* (ripe *coreya arborea*), and bhatiga (a common intoxicating drug), the skin of a snake and fish, and the powder of the nails and tusk of an elephant, all mixed with the and *kodrava* (*paspalam scrobiculatum*) or with the chaff of the seeds of hastikararana (castor oil tree) and palasa (*butea frondosa*) causes immediate death wherever the smoke is carried off by the wind."[8] It is evident that the invention is quite complex to produce, with ingredients that are not commonly found. Items such as pigeon dung, frogs, and snake skin are rare in most chemical preparations. However, these were among the most commonly used techniques for preparing drugs and poisons in ancient times and also in medieval times.

Minerals, metals, jewels, and gems are used by ancient Hindus to treat fetal diseases. Difficult composition for chemicals was carried out before preparing a concoction. During oxidation or reduction processes of metals, forms *bhasms,* those are occasionally converted into biologically active nanoparticles.[9] The idea of decreasing particle size was taming the usefulness of a drug is mentioned in *Caraka-Samhita*. At high temperatures, plant extracts are quenched with metals to form a dust-like (nanoparticle) powder with chemical properties. The *bhasmas* should be glow less if the method was successful. As metals have a property of luster, so lusterless property indicates the transformation has been done. The alchemical practices of the Hindus are mentioned by Al-Biruni.[10]

In *The Lure and Romance of Alchemy,*[11] Charles Thompson wrote, "In India the earliest allusions to alchemical ideas appear in the Atharva Veda, where mention is made of the gold that is born from fire." In the *Rgveda, Sura* is described as an intoxicating drink consumed alongside soma. In India, the term *sura* is refers to alcoholic beverages. In the fermentation section, we have discussed this in detail.

Chyawanprash is a widely used rejuvenating tonic in India, particularly in northern regions, where it is taken as a precautionary measure against the common cold during the winter season. The use of Cyavanaprash dates back to ancient times, as Caraka mentioned it for rejuvenation. In his *Caraka-Samhita*, Caraka also mentioned the syrups that contain iron. These syrups are famous as the "killing of metal" and the resultant product of those synthesized compounds is recognized as *bhasma* in Sanskrit. Caraka suggested how to achieve the removal of iron: using very thin sheets of iron, extract of Indian gooseberry (*amla*), and an underground jar with honey for a year, which form a ferrous compound from iron, as a result decreasing the amount of iron. Those are mainly processes of making nontoxic metals. Additionally, an entire chapter by Susruta is written about how alkalis are used to treat several diseases, like mucous-destroying, digestive, and virility-diminishing properties.

The above-mentioned phenomena are related to the medicinal purpose of chemistry, where most of the health issues were resolved by chemical procedures. Apart from that part, chemistry, or the chemical processes, deeply enhanced the upgradation towards the civilization in ancient India. The main three parts are as follows: a. mining and metallurgy; b. fermentation; c. wootz.

Metallurgy and mining :

Ancient Hindus were pioneers in mining and metallurgical advancements to produce excellent Damascus steel. Steel was referred to as "*foulade Hind*", signifying the Indian steel. Likewise, after Alexander the Great's conquest of Porus, he acknowledged steel as a valuable gift, something that the Greeks do not have. Aristotle mentions in *On Marvelous Things Heard*, that the Indian copper is renowned for its quality and is said to be "indistinguishable from gold".[12] This reference likely acknowledges the quality that is exceptional for Indian bronze, which is made with copper mixed with zinc and other metals, which gave it a gold-like appearance.

In the Rgveda, the smelting process is described as the ore was located in bellows, and fire was used to intensify the temperature. The *Atharvaveda* mentions that the middle of the earth, which holds the gold, suggests the existence of mining operations and the mines of gold. In India, several ancient metals including gold, silver, iron, lead, and copper, were naturally found in many regions. The residues of Harappa and Mohenjodaro include decorated pottery and sheets of metal. Metals such as bronze, iron, gold, silver, lead, and copper were used to create a variety of items, including axes, spears, arrowheads, daggers, knives, swords, drills, metal mirrors, and cooking and storage utensils. Out of 324 objects analyzed from archaeological sites, among them approximately 184 are made of pure copper. Additionally, four copper processing kilns have been uncovered at the locations of Mohenjodaro, Harappa, and Lothal.[13]

Timber was collected from an ancient mine in Hutti, Karnataka, which was a depth of approximately 200 meters. After carbon dating analysis it shows that the area is nearly about 4th century BC.[14] Greek tourist Ktesias, residing in Persia at the time of 5th century BC, refers to large quantities of gold extracted from "high-towering mountains" and also describes a congealing process used to obtain high quality gold.[15] Many historians, specially Greek including Arrian, Ktesias, Megasthenes, and Herodotus, stated that in India people are using metals. The brass samples from Taxila around 3rd to 4th century BC reveals due to the 35-40% presence of zinc gives golden texture. Remarkably, smelting technicians in India developed an advanced method to obtain purified zinc, although this type of extraction techniques were not experienced in Europe until 16th century. A distillation process (downward) where zinc was smelted and the vapors of zinc were rapidly cooled to prevent the reduction process that occurs at higher temperatures. The main challenge was that zinc oxide requires at least 1150º C temperature for reduction, while zinc has a boiling point of 900º C, causing it to vaporize and escape. The furnaces excavated at Zawar (Rajasthan) feature 2 chambers, up and down, divided by a heavy perforated brick plate. The above chamber is sealed, directing the vapor into the bottom chamber, which was filled with water. The water decreased the temperature and solidified the zinc. In 600 BC, the "Painted Grey Ware of the Gangetic Valley" was build. A couple of glass bangles discovered at Hastinapur, New Delhi, were from 1100-800 BC. Comparable green-colored bangles have also been found in other parts of northern India.[16] Glass bangles remain a popular form of ornamental jewelry worn by Hindu women to this day. Also around 700-600 BC, cuprous oxide coloring green glass was found in Taxila known by dating.

Kautilya understood the state's economy will be gained from mining. Then he proposed "mines are the source of treasury; from treasury comes the power of government."[8] He also outlined the responsibilities of the Mine Director: "must possess the knowledge of the science dealing with copper and other minerals, experienced in the art of distillation and condensation of mercury and of testing gems, aided by experts in mineralogy and equipped with mining laborers and necessary instruments, the Director of mines shall examine mines which, on account of their containing mineral excrement, crucibles, charcoal, and ashes, may appear to have been once exploited or which may be newly discovered on plains or mountain slopes possessing mineral ores, the richness of which can be ascertained by weight, depth of color, piercing smell, and taste."[8] Kautilya provided guidance on identifying promising mining locations: by observing soil, stones, or water blended with metals, particularly if the color of the object is bright or is heavy, or it emits a strong odor, which could indicate a nearby mine may be present. He outlined methods for locating mines of copper, glass, iron, silver, and gold. The mining operations was required to have knowledge of metallurgy, chemistry, and refining processes. This suggests metallurgy was a well-established area in India at the 3rd century BC. Additionally, Kautilya set ethical standards for goldsmiths, imposing severe penalties on those who unfairly mixed gold. Slightly low-priced impurities such as copper, brass, and tin mixed at the time of melting of silver and gold was deliberated a corruption, and the offenders were prosecuted and even the thieves who stole minerals were also prosecuted. Kautilya described the ores of arsenic, silver, iron, copper, gold, tin, and lead, along with their purification processes. At that time coins were used for business purpose. Kautilya also outlined the methods used by counterfeit coin manufacturers and specified a penalty for coin examiners who accepted counterfeit coins into the treasury.

Kautilya defined gold percentage in a sample as varying up to sixteen different gold standards, which is comparable to the modern "carat" method. Copper was alloyed with gold to create different carat standards.[8] Kautilya defined several gold alloys in various colors, including yellow, blue, white, red, and green, attained by gold-containing substances like salt (rock), copper, lead, mercury, and silver. The chemical reactions involved were precisely outlined, specifying exact ratios of each component. Metal plating (gold plating) methods were described, including heating processes, mica, rock salt, wax, utilizing amalgams, and more. Additionally, Kautilya established standards for testing precious stones, including criteria for color, weight, and characteristics, as well as methods such as cutting, hammering, scratching, and rubbing.

In New Delhi, the Iron Pillar near Qutub Minar stands as a testament to the advanced metal-imitating abilities of ancient Hindus. Inscription in the pillar mentioned the era between 400-450 CE, it indicates King Candra's period. Inscription shows minimal corrosion despite being exposed to the elements for over 1600 years. Even in the heavy rains, air, and heat, the pillar has not suffered substantial rusting, despite the very high heat and humidity condition in July and September. The pillar remains an enduring symbol of the exceptional engineering and metallurgical skills of ancient Hindus. Later in 1739 CE, when the city occupied Nadir Shah, he attempted to destroy the pillar with cannons but unsuccessful. Some marks remain where the cannon-balls struck the pillar. The pillar stands at 7.16 meters (23 feet 6 inches) in height, with a diameter of 16.4 inches at the base and about 11.8 inches at the top. Highly pure iron is not available in Indian mines, suggesting that a refining process was involved in the creation of this pillar. A very fine protective coating of Fe_3O4 given in the pillar to achieve through the use of salts and quenching. The buried portion, when excavated, revealed that the base of the pillar was protected with a sheet of lead, approximately 3 mm in thickness. The Sun Temple in Orissa and the Iron Pillar of Dhar, Madhya Pradesh, both are made by similar kind of manufacture technique. Eventually both places are in comparatively humid areas with very low rusting. The phosphorus percentage in the iron may be the cause.

Recent research has uncovered the reason of rust free pillar. The combination of iron with phosphorus is the key factor. The surface becomes porous when it gets rust, which allows the phosphorus to form phosphoric acid via reacting with other compounds. Then iron reacts with this acid to form dihydrogen phosphate. Both of these kinds of phosphates are insoluble in polar solvents like water and amorphous. This amorphous phosphate interacts with metal ions and turns into ferric phosphates, which are crystalline. It remarkably reduces the surface porosity, and as a consequence of that, rusting on the iron is reduced. So only phosphorus is responsible for the rust-free pillar.

Fermentation:

The main component of beer is fermented barley mentioned in *Rgveda:* "A mixture of a thick juice of soma with barley powder."[2] Also added that: "Fifteenth day old highly intoxicating soma,"[2] 84 different kind of alcoholic liquors are mentioned by Caraka.[17] Caraka also said in the fermentation process, several resources of sugar, including sweet palmyra sap, sugarcane juice, honey, jaggery, mahua flowers, and coconut water. Additionally, apricots, grapes, bananas, dates, mangoes, rose apples, jackfruit, jamun, bilva, pomegranates, kadamba, and others sweet fruits were also used. Grains, mainly barley and rice, were employed in the fermentation process. By the time of Kautilya, a liquor supervisor was appointed to oversee the industry. The production of liquor and the regulation of its movement across borders were closely monitored.

Few fermented broth was used in medical treatment. Kautilya suggested that patients should be taught by physicians how to prepare these *arista* (distilled and fermented liquor). He mentioned various recipes: "one hundred pala of *kapittha* (*Feronia Elephantum*), 500 pala (mass) of sugar, and one prastha (mass) of honey form *asava*."[18] It was also recommended to use a few hard liquors made from lentils and rice: "one drona of either boiled or unboiled paste of *masa* (*Phraseolus Radiatus*), three parts more of rice, and one karsa of *morata* (*Alangium salviifolium*) and the like form *kinva* (ferment)."[19] To increase the taste of the liquors, additives were added, including spices, astringents, and sweeteners. The variety of additives added mentioned in the *Arthashastra* and *Caraka-samhita* are equivalent to the variety available in the market today.

Wootz:

The term "steel" comes since the times of 11th century CE from the name *stahal* in German, which is linked to the Sanskrit word *stakati*, meaning "it resists" or "strike against." Manufacturing the sword it was very commonly used because of its hardness. Very little (0.10 to 1.5%) carbon (mainly Fe_3C) containing alloy is steel. The characteristics of steel differ significantly by changing in small quantity in carbon content. Depends on their desired characteristics, few metals like vanadium, manganese, chromium, silicon, molybdenum, and nickel, are purposely mixed during the process e.g. tungsten steel contains more tungsten to increase its melting point and heat tolerance, while stainless steel typically contains around 12% of chromium or higher. In India, steel has been prepared and used for numerous purposes since ancient times.[20] A. Kumar mentioned in his book *Ancient Hindu Science:* "Ktesias, who was at the court of Persia during the 5th century BC, mentioned the two high-quality Indian steel swords that were presented to him. One sword was presented by the King of Persia, and the other by king's mother, Parysatis."[21] An army officer in Alexander the Great's, named Nearchus, noted that Indians typically carried a broad sword about three cubits long.[22]

King Porus, a ruler from Punjab, was defeated in battle by Alexander the Great and captured. When brought before Alexander's court, the conqueror asked in what way he should be treated. Porus answered, "Like a king." This response surprised Alexander and made him realize the futility of wars. In an uncommon move, Alexander decided to release Porus and return his empire, as defeated kings were typically either killed or imprisoned. Grateful for his life, Porus sought to express his gratitude to Alexander. He chose to gift something truly priceless—more valuable than gold, gems, or spices—that Alexander did not have. Porus decided to present 6000 pounds[23] of steel, like a priceless gift, according to Roman historian Quintus Curtius, from the 1st century CE mentioned in the biography of Alexander the Great. Curtius referred to steel as "ferrum candidum", meaning "white iron."[23]

In India, steel, known as wootz, was traded as castings or cakes, which were approximately the size of ice hockey pucks.[24] Persians mistakenly referred to Damascus steel/sword; before that, they were made swords from wootz. Similarly, Europeans discovered steel-making techniques in 1192 CE at the time of the Crusades.[25] The extraordinary strength and hardness of the steel impressed them, prompting a desire to uncover the secrets of producing ultra-high carbon steel. However, the Europeans were unaware that the procedure had initiated in India. Steel manufacture was initially very difficult because of the large fuel consumption needed for extremely high temperatures to form molten components. After 1850 CE, advanced furnace technology at high temperature the process. As a result, steel was primarily used for manufacturing blades for swords, daggers, and knives. Damascus steel is known for its distinctive swirling surface pattern, which results from the cooling process. These patterns are created by the alignment of Fe_3C components on the surface at the time of cooling. Consequently, Damascus steel/swords became renowned for their hardness and absorption power of blows, making them reliable weapons that the soldiers could depend on during battle in the Middle Ages.

Making wootz steel is a very difficult procedure, as even tiny impurities can alter the final outcome. The cooling period and temperature also significantly vary the quality of the steel. In 1589 CE, an Italian scholar, Giambattista della Porta, from Naples, highlighted the implication on temperature by handling wootz and advised avoiding "too much heat."[26] Later, the Stanford University's researchers Jeffrey Wadsworth and Oleg D. Sherby discovered that to produce very high-quality steel is to slow down the equilibrium cooling. At 1200º C, iron and carbon form a molten state of the steel, and then lowering the temperature spreads the carbon throughout the iron and produces white cementite forms due to the arrangement of Fe_3C (cementite) particles. Polishing reveals Fe_3C materials as white against the nearly black steel medium. These carbide components strengthen the steel without making it brittle. To harden the blade, it was heated to 727º C, causing crystal structure modification. The iron atoms are converted to a face-centered from a body-centered lattice. The knife/sword blade was subsequently plunged into water to be quenched.[25] However, the metals become fragile if before quenching, heating was done over 800º C.

Michael Faraday (1791-1867), a pioneer in electromagnetic discoveries, attempted to replicate Damascus steel but mistakenly concluded that aluminum oxide and silica enhanced the steel's properties. With Stodart he also tried to create steel via alloying nickel with silver and platinum, but their efforts proved unsuccessful. Therefore, the steel manufacturing technology developed in ancient India was far superior to that of European scientists until the 19th century.[21,27]

Conclusions:

It is very much clear from the above discussion is that in ancient India people are used chemistry in daily life especially for health purpose and then after various technology developed using chemistry. Many diverse applications i.e. steel, metallurgy, alcoholic beverage had been found in that period without significant literature data. Eventually few pure sculptures had been made that period which never been done till date.

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