

Trace Elements

Affecting Health, Moulding Materials

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DIFFERENT materials behave in different ways. But what makes a material suitable for a particular application? The quality of all materials depends mainly on their composition – the concentration of constituent elements and their crystal structure. Often, the purity of materials is also a very important factor in their application and quality.

Elements present in very small concentrations, either as impurities or added intentionally, also affect the quality of materials. These elements present in small quantities are known as trace elements or ultra trace elements depending on their concentration. Generally an element with concentration less than 100 parts per million (ppm) is considered a trace element and those with less than 1 ppm levels are known as ultra trace elements.

Unwanted trace elements are regulated to keep their concentration levels below certain limits as these deteriorate the quality of materials if present above this limit. On the other hand, certain trace elements are essential for some materials to functional well.

The presence of trace elements in our blood and other body fluids can also give an indication about the diseases present in our body and also indicate the way to treat such diseases.

Trace elements in biological systems

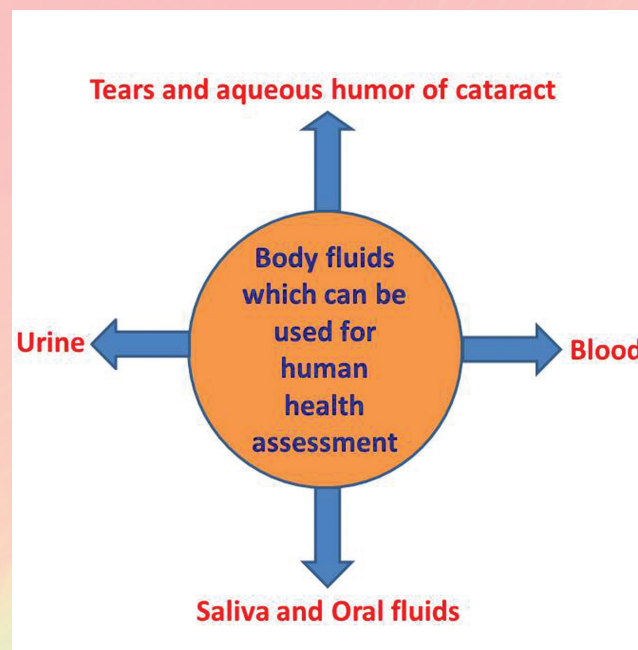
Our health depends on the quality of blood flowing in our arteries and veins. Often if the concentration of certain elements in our blood falls lower than the specified limits, it becomes necessary to add these elements in the form of dietary supplements to keep the body working optimally.

An example is the requirement of Calcium (Ca). The normal level of Ca in human body is in ppm levels. When the Ca level in blood decreases it draws Ca from the bones and if it increases it transfers it to the bones. Low level of Ca intake may lead to pain in the muscles, numbness or cramps. However, large amounts may lead to stones in kidney, constipation or sometimes heart related problems. The amount of Ca in the body is assessed by analyzing the blood.

Similarly, for assessing the body health condition it is also essential to determine the levels of elements such as O, Na, Mg, K, Cr, Fe, Zn, Se, Pb, Hg, U, etc. A concentration of $10\text{ }\mu\text{g}$ Pb/deciliter in children's blood may lead to decrease in IQ. Significant differences in Zinc, Chromium, Cobalt, Manganese, Barium, and Lead between diabetic and non-diabetic patients have been observed.

Other body fluids e.g. saliva, blood plasma, tears, urine, tears, aqueous humor of cataract and dental plaque, nails,

and hair can also serve to assess the levels of trace elements in our body in a painless manner. Such analysis can also give information about the cause of death by suspicious poisoning and may be helpful in forensic sciences also.



Some body fluids that can be used to monitor human health condition by analyzing them for trace elements

Trace elements in food

Trace elements necessary to keep our body fit to function in an optimum manner are obtained from food. For instance, specific amounts of Selenium (Se) in blood is needed to increase body immunity as it is an antioxidant, antiviral and anticancer agent. In recent studies it has been found that people with adequate Se levels in blood had low mortality rate due to Covid-19. However, high Se may lead to stomach upset, hair loss or even heart attacks.

An important source of Se is wheat which contains Se in ppm levels. The cost of Se-rich wheat is higher as compared to Se-deficient wheat. It is reported that Selenium content in wheat is in the range of $0\text{--}8270\text{ }\mu\text{g kg}^{-1}$. The normal level of selenium in human blood is $110\text{ to }165\text{ }\mu\text{g kg}^{-1}$. Almost 80% of the world population has low levels of Selenium.

Similarly, some other elements like K, Mg, Fe, Cu, Zn up to a certain concentration levels in food are required as nutrients whereas elements like Cr, As, Pb, Sb, U, etc. are toxic and cannot be tolerated in human body above certain concentration levels (a few ppm only).

Table 1. Some trace elements in human body and their advantages/toxicity for human health

Elements	Approximate daily intake required for human body	Major sources	Main function	Toxicity, if consumed in excess
Ca	1000 mg	Dairy products, green leafy vegetables, nuts like almonds, grains, etc.	Bone health, muscle contraction, blood clotting, etc.	Kidney stones and diseases, Constipation
Zn	14-30 mg	Meat, fish, seafood, milk, cheese, peanuts, rice, shrimp	Enhancing immune function, wound healing, child growth	Nausea and vomiting, diarrhea, abdominal cramps, low HDL cholesterol
Mg	320-400 mg	Pumpkin seeds, almonds, spinach, cashew nuts, potatoes	Protein buildup, regulating blood pressure, heart beat stabilizer	Nausea, vomiting, diarrhea, depression, muscle weakness, low blood pressure, abnormal heartbeat
Se	70 – 400 µg	Tuna fish, brazil nuts, chicken, rice, egg, wheat	Prevents cancer, thyroid disorder, cardiac problems	Lesions of the skin and nervous system, nausea, diarrhea, skin rashes, fatigue, irritability, and nervous system abnormalities
Cu	1100-1400 µg	Seafood, nuts like cashews and almonds, mushrooms, tomatoes, potatoes	Helps to make red blood cells. keeps nerve and blood cells healthy, helps body to absorb iron	Nausea, vomiting, stomach pain, headache, weakness, diarrhea, metallic taste in the mouth
Na	2.3 g	Table salt, fruits, vegetables, oils, and cereals	Regulation of fluid and electrolyte balance and blood pressure (BP)	Hypertension, cardiovascular diseases (CVDs), chronic kidney disease, osteoporosis, heart failure, liver cirrhosis and renal failure
K	2.3-3.4 g	Dried fruits, potatoes, spinach, avocado, bananas	Helps heartbeat to stay regular and move nutrients to cells, offsets some of sodium's harmful effects on blood pressure	Can damage heart and cause heart attack, kidney disease, diabetes

Trace elements in air and water

While the food we eat must contain necessary trace elements, the air we breathe in should be as pure as possible. However, the air around us often gets contaminated with smoke and dust, ashes and gases from volcanic eruptions, or methane from decomposing organic matter in soils.

Trace elements in air cause breathing and other health problems even at much smaller concentrations. These elements float in the air in the form of particulate matter (PM) of micron sizes. The PM effect on health depends on the size of the particulate matter. PM with diameter less than 10 micron is known as PM₁₀ whereas those

with diameter less than 5 micron are known PM₅ and so on.

Particulate matters are medium of transport of trace metals in air, in addition to viruses. Presence of large amounts of aerosol in atmosphere is undesirable. Elements Si, Al, Ca, etc. originate in air from natural sources whereas S, Zn Pb, Cr, Fe, etc. originate from anthropogenic sources. Trace elements like Zn, Fe, Cu, Mn, Pb, Ni, Cr, As, Cd and Co have been reported in mining and industrial areas in concentration range of a few 100 pg/M³ to a few thousands nanogram per M³ volume of air.

In addition, the smaller particles are more harmful to health than the larger one as smaller particles penetrate deep into the lungs. Though the amounts of trace elements present in aerosol particles are very small (nanogram to microgram level), through continuous breathing we inhale a large amount of such elements into our lungs affects their capacity.

Presence of heavy metals e.g. Pb, Cd, Hg, in air can lead to toxicity in our body and may lead to cancer, damage to nervous system, kidney, lung and liver diseases and sometimes even death. The trace levels of toxic metals in the lungs obstruct gas exchange, get leached out and enter into the blood stream. Presence of arsenic in air at trace levels leads to respiratory tract disorders and skin ailments. Phosphorous (from combustion emissions and mineral dust) and Cadmium (from volcanic eruptions) also cause cancer even if present at trace levels in human body.

Similar is the case of trace metals in water. Trace metals like As, Pb, Cr, Hg, U, etc. present in water are adversely affecting the health of a large population in the world.

Trace metals in industrial materials

Materials used in industries or utilized in strategic applications should not have impurities beyond a certain specified range. For instance, steel is extensively used in household items and often used as an advanced technological material used in power plants as structural material and nuclear reactors as cladding materials. Today, steel is also being produced from recycling of scrap materials – but this steel produced is contaminated with residual trace elements. These impurities affect the quality of the steel produced.

Often some elements are added intentionally to enhance the properties of steel whereas some elements are unwanted even at trace levels. The elements which are added to enhance the properties are known as alloying elements, e.g. copper, nickel, chromium, molybdenum, aluminum, vanadium, niobium, boron, cobalt, tungsten, etc.

Carbon is an important element which is added intentionally in steel manufacturing. The presence of carbon increases the hardness of steel and decreases its ductility. Due to this reason the amount of carbon in steel should be in the range of 50 to 9000 ppm depending on the type of steel usage. Similarly, Mn and Cr are also required in different amounts in steel for enhancing certain properties. But elements like S, P, Sn, Pb, Zn, Sb, Cd and Hg are unwanted and their concentration should be below a certain level. For instance,

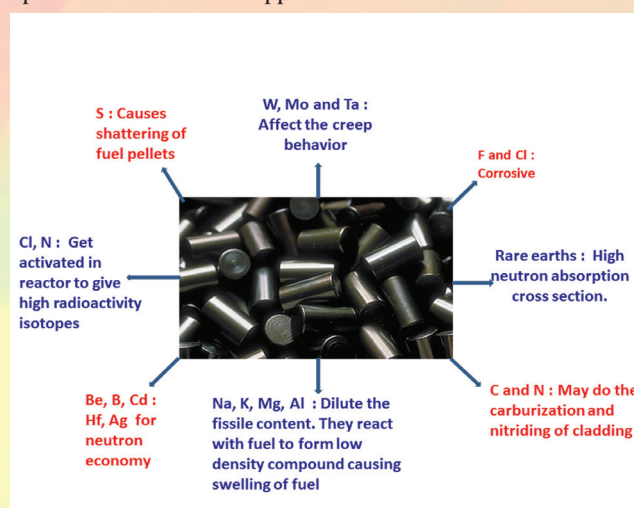
S should not be present more than 0.0015 to 0.03% range in different types of steels as it adversely affects the surface quality of steel in addition to P and Zn.

Trace Elements in Nuclear Fuel and Materials

Nuclear Energy is one of the clean options of energy production. Energy is produced by the fission of a heavy nucleus viz. ²³⁵U or ²³⁹Pu. During the fission process the nucleus of the target atom breaks into two nuclei and neutrons, which cause further fission and so on. This results in a propagating chain fission reaction.

The target nuclei undergoing fission is known as fissile nuclei and is used as nuclear fuel in the reactor to produce power and for research. Thus neutrons are very important inputs for efficient operation of a nuclear reactor. The nuclear fuel is normally taken as metal or oxide of uranium and plutonium in form of pellets covered with metal claddings. Trace elements in the nuclear fuel can severely affect the working of the reactor.

Similarly common impurities like Na, Mg, Al dilute the fissile material content of nuclear fuel and affect the physical properties of structural materials. Due to this reason, the concentration of trace elements in the fuel should be below specified values. The specified concentration of B for different fuels in different reactors is 0.3 to 2 ppm whereas for Cd these values are 0.2 to 6 ppm. Due to corrosive nature of F, its specifications are 10-25 ppm for different reactors.



Depiction of effect of some trace elements on nuclear fuel and structural materials of a reactor

So, trace elements do not just play an important role in human health, they are also important in maintaining quality control of materials and processes.

Acknowledgements: The author expresses his sincere thanks to Dr B.S. Tamar and Dr Mithilesh Kumar for their constructive discussion and suggestion during preparation of manuscript of this article.

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