Application of Chemical Principles to some Industries in Sri Lanka

Prof. H.D. Gunawardhana

Introduction

The industries involve the application of technologies to produce materials for our needs. The survival of a particular technology is dependent on the applications of the associated sciences. One could argue that ancient Sri Lanka had only the technology, which helped in the booming of the economy from time to time with the assistance of good governance. It is clear that the ancient technology was based on some form of unwritten science surely not the modern science. Due to historical reasons most of the ancient unwritten sciences died off leaving us to apply the 'modern science' to ancient as well as modern technology. Therefore, the application of modern science to technology is essential since the sustainable development of a country is based on the improvement of the technologies. Principles of Science → Technology → To fulfill the technological needs of a country → Development of Knowledge Economy The application of the principles of science to technology becomes fruitful if there is a scientific culture in a country where Education in Science and Technology plays a vital role. The following aspects can be highlighted and these may be considered as the key factors required to achieve a scientific culture in Sri Lanka.

The Dependency of Technology on Science

The Nobel Prizes are awarded for three scientific disciplines namely, **Physics, Chemistry and Medicine.** The international scientific community has recognized that these three scientific disciplines would be responsible for the advancement of technological areas such as:

Engineering – the application of the concepts associated mainly in physics.

Biology – the application of chemistry and physics.

Mathematics and Computer Science can be considered as tools which are essential for the advancement of physics, chemistry and medicine.

The Watson and Crick paper titled "A Structure for Deoxyribose Nucleic Acid (DNA)" written on the 2nd of April, 1953 was published in "Nature". In 1962 Watson, Crick and Wilkins received the Nobel Prize in Physiology or Medicine. The people responsible for the discovery of the double-helical structure of DNA were Francis Crick, Rosalind Franklin, Linus Pauling, James Watson and Maurice Wilkins. It could be said that one important aspect of biology, the structure of DNA was discovered by physicists and chemists. The background knowledge in physics assisted them work out double helical structure of DNA.

An industry involves the conversion of raw materials to useful product(s). If the manufacturing process is carried out at a constant pressure the Gibbs Free energy change ($\Delta G^{\oplus}$) is mostly a positive value. That is, most reactions in manufacturing industry are non-

spontaneous. Therefore, an energy input is essential to overcome the positive value of Gibbs energy. The natural Industry is photosynthesis, which produces useful products i.e. carbohydrates.

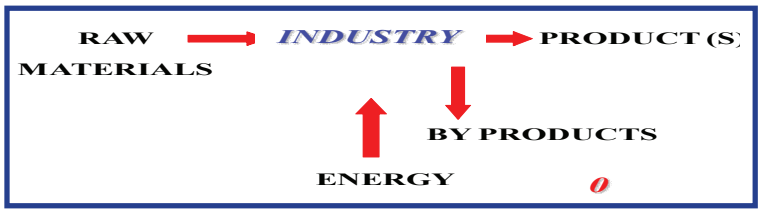


Figure 1 Operating principles of an industy

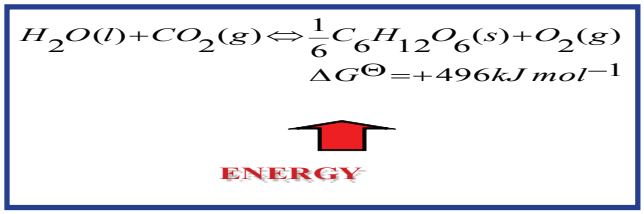


Figure 2 Photosynthesis as a Natural Industry

Since the Gibbs energy change is positive for photosynthesis (i.e. +496 kJ mol-1) an external energy (solar energy, is essential to push the reaction forward. Therefore, thermodynamics is applied to photosynthesis. Not only thermodynamics but also quantum mechanics which involves an electron transfer from HOMO to LUMO in photosynthesis. This is an example of a 'Natural Industry'. Another useful phenomenon in Biology and Physiology is Osmosis, which is the movement of water molecules from an area of low salt concentration to an area of high salt concentration. The salt concentration of a plant or animal cell is very high. The cell membranes are completely permeable to water. When a cell is placed in a solution of low salt concentration (e.g. distilled water) the water diffuses into the cell, causing the death of the cell. When a salt is dissolved in pure water the chemical potential (μ) of the pure water decreases. This leads to the spontaneous movement of water molecules through the semi-permeable cell membrane since the Gibbs free energy change for this movement is negative.

When the pressure is applied against the direction of osmotic movement then the osmotic flow will be slowed or even reversed (reverse osmosis). When the pressure is just enough to stop the osmotic flow an equilibrium is reached. This is called the 'Osmotic Pressure'. It is obvious that Chemistry plays a vital role in all aspects of biology and physiology (medicine). There are several examples of this nature where the principles of physics and chemistry can be meaningfully applied. The teaching of scientific subjects should be geared in such a way that the students will develop the capability to apply principles of science to industry, medicine (Physiology), laboratory and even day to day life.

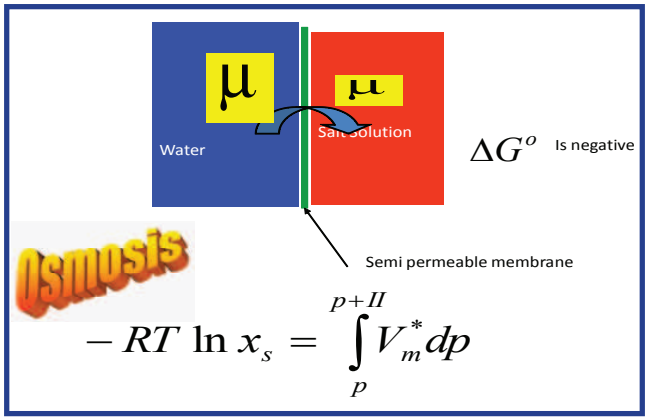


Figure 3 The pure solvent has termodynamic tendency to flow into the solution

The application of scientific principles is not only for the manufacturing process but is also associated with environmental standards in their management processes. Some standards for the discharge of industrial effluents are listed in the Table 1.

Chemical Oxygen Demand(COD) (Table 1) is a well known water pollution parameter for industries but a student who offers chemistry as a subject at GCE(A/L) cannot understand SLSI standard given in Table 1.

$$(CHO)_n(aq) + O_2(aq) \rightarrow xCO_2(g) + yH_2O(l)$$

Amount of oxygen required in mg dm-3 for this oxidation to be carried out chemically is called Chemical Oxygen Demand (COD)

Amount of oxygen required in mg dm-3 for this oxidation to be carried out by microorganisms is called Biochemical Oxygen Demand (BOD)

Table 1 Tolerance limits for the discharge of effluents ; Sri Lanka Standard Institution(SLSI) ?

No.	Determinant	Tolerance limits for effluents discharged into surface waters	Tolerance limits for effluents discharged into marine coastal waters	Tolerance limits for effluents discharged on land for irrigation purpose.
1	pH	6.0 – 8.5	6.0 – 8.5	5.5 – 9.0
2	Temperature, °C	40	45	35
3	BOD. mg dm^{-3}	60	100	250 (100)
4	COD, mg dm^{-3}	400 (250)	400 (250)	650 (300)
5	Chloride, mg dm^{-3}	1000	Not applicable	-
6	Chromium(VI), mg dm^{-3}	0.5	0.5	0.5
7	Chromium(Total),mg dm^{-3}	2.0	2.0	2.0
8	Sulfide, mg dm^{-3}	2.0	5.0	-

Teaching of Chemical Principles as applied to day to day life, laboratory and Environment and **EVALUATION** geared towards the testing of the ability to use the knowledge when the need arises will undoubtedly fulfill the above needs. Does the traditional Chemical Education in Sri Lanka provide the TRAINING to use the knowledge when the need arises? It mainly provides students to imagine the so called TEXT BOOK Chemistry. There are several examples where the knowledge is confined to text books and not the applications to laboratory or day to day life. Some examples are cited below:

Dissolution of common salt in the kitchen NaCl(s)

$$NaCl(s) \longrightarrow Na^{+}(aq) + Cl^{-}(aq)$$

This is spontaneous and therefore, ΔG should be negative value. The positive value for ΔH can be observed if a large quantity of common salt is dissolved in a stainless steel container.

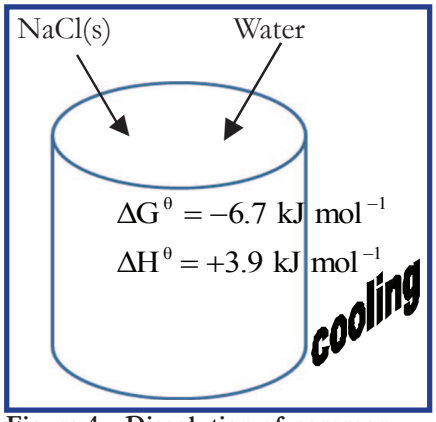


Figure 4 Dissolution of common salt in a steel cup

Dissolution of sugar in a cup of tea:
This is spontaneous and therefore, ΔG should be negative value.

$$C_{12}H_{22}O_{11}(s) \rightarrow C_{12}H_{22}O_{11}(aq)$$

Hydration of Dolomitic Quick-lime

$$CaO.MgO\,(s) + 2H_2O(l) \rightarrow Ca(OH)_2.Mg(OH)_2(aq)$$

This is spontaneous and therefore, ΔG should be a negative value. The negative value for ΔH can be observed easily which involves heating. Slaking (hydration)of 1 kg of dolomitic quick-lime is sufficient to boil 500 cm^3 of water.

Energy generation in the kitchen

$$C_nH_{2n+2}(l\,or\,g) + O_2(g) \rightarrow xH_2O(g) + yCO_2(g)$$
$$(CHO)_n(s) + O_2(g) \rightarrow xH_2O(g) + yCO_2(g)$$

This is spontaneous and therefore, ΔG should be negative value. The negative value for ΔH can be observed in the flame. The Flame is the area where the above reactions occur.

If the environment is affected it creates an undesirable effect on the society. The students of chemistry are a part of the Society and should be in a position to address the Society with the help of the units given in the standard and also the units understood by the society.

Following examples illustrate the units.

50 mg dm^{-3} of NO^-_3 ≡ 8x10 $^{-4}$ mol dm^{-3} ≡ 11.3 mg dm^{-3} of NO^-_3 - N ≡ 0.008 cmol dm^{-3}

200 mg dm^{-3} of C_a^{2+} ≡ 5x10^{-3} mol dm^{-3} ≡ 1x10^{-2} cmol dm^{-3}

Industries should be advised to reuse the water

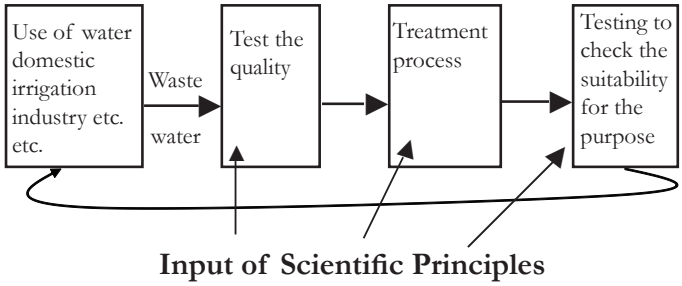


Figure 5 Recycling of water

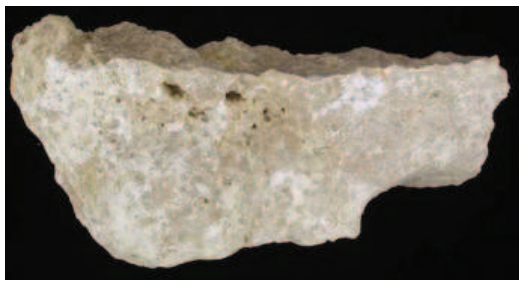
Chemical principles in the value addition of some industrial minerals of Sri Lanka

1. Lime stones

- Miocene Lime stone – mainly calcium carbonate
- Crystalline lime stone – dolomite, calcite, magnesite etc.
- Shell, Coral (Animal origin)

Some uses of lime stones are: Cement (Miocene Lime stone), Construction industry (Calcite, Dolomite), Paint (Shell),Food industry (Coral) etc. Coral is a very pure form of calcium carbonate. Coral was used for construction industry where such purity is not required. " Not sustainable consumption".

"Limestone" available in the Central Province to manufacture cement is not suitable for the manufacture of cement due to its high magnesium content.



Limestone

2. Apatite –Eppawala apatite

It is estimated that this deposit (discovered in 1971) contains 60 million tons which is adequate for sustainable consumption as a phosphate fertilizer required for several generations. Despite this discovery, it is unfortunate that Sri Lanka still imports triple super phosphate (TSP) spending several million rupees annually. The technology for the conversion of apatite to super phosphate and TSP is well known.

$$[3Ca_3(PO_4)_2].CaF_2 + 7H_2SO_4 + H_2O \rightarrow 3\,Ca(H_2PO_4)_2 + 7CaSO_4 + 2HF$$

Superphosphate

With excess sulphuric acid Triple Superphosphate (TSP) is formed.

$$[3Ca_3(PO_4)_2].CaF_2 + 10H_2SO_4 + 20H_2O \rightarrow 6H_3PO_4 + 10CaSO_4.2H_2O + 2HF$$

$$3SiF_4 + 2H_2O \rightarrow 2H_2SiF_6 + SiO_2$$

$$[3\,Ca_3(PO_4)_2].CaF_2 + 14\,H_3PO_4 + 20H_2O \rightarrow 10\,CaH_4(PO_4)_2.H_2O + 2HF$$

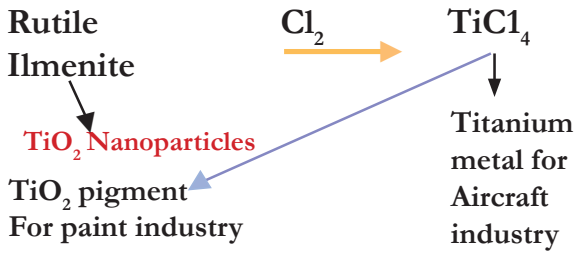
3. Silica based minerals – Quartz, granite etc. Reserves of quartz were estimated to be adequate at more than 20 million metric tons

4. Mineral sands - Rutile, ilmenite, ziron, monazite etc. Beach sand containing Ilmenite, Rutile, Magnetite, Zircon, Monazite and Silica. These resources based at Pulmoddai are replenished annually (15%) with the advent of the north-east monsoon season. Utilising around 150,000 tons per annum for an upgrading plant, the reserve can last for over 25 years. Four million tons of heavy mineral sands (grades of over 60% heavy mineral) are available in Pulmoddai. This deposit rates among the best known in the world, especially due to its heavy mineral contents of between 60% to 70%. India is looking to buy more rutile and ilmenite mineral sands from Sri Lanka. It is said two state-run firms Kerala Minerals and Metals Ltd and Travancore Titanium Products Ltd were looking to import more mineral sands from Sri Lanka. Ilmenite and rutile are used to produce Titanium metal used in the aerospace industry, and Titanium dioxide pigment, used in paints. In 2008, China was the biggest buyer of Sri Lankan mineral sands, followed by India. Large mineral resources are found in the eastern coast of Sri Lanka, where a 30-year war ended this year. The sands are extracted by state-run Lanka Mineral Sands.

Ilmenite

Monazite

TiO_2 pigment is used in paint industry Titanium metal is used in aircraft industry.



Zircon ($ZrSiO_4$)
Some uses of Zirconium metal are,

(a) Nuclear power plants,
(b) Items, e.g. Zirconium crucibles

Monazite: A reddish-brown phosphate mineral containing rare-earth metals, (Ce, La, Y, Th)PO_4, important as a source of cerium and thorium is found in **Benthara Ganga Area.** Thorium can be converted into a nuclear fuel Uranium -233 (^{233}U).

Nuclear fuel is a material that can be consumed to derive nuclear energy.

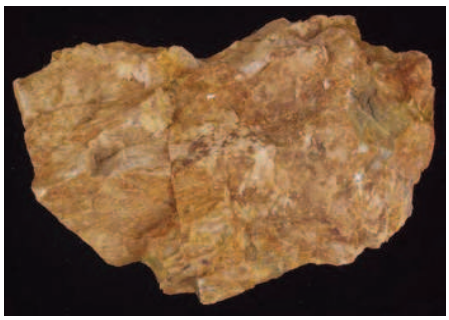
$$^{232}_{90}Th + ^{1}_{0}n \rightarrow ^{233}_{90}Th + \gamma$$

$$^{233}_{90}Th \rightarrow ^{233}_{91}Pa + \beta$$

$$^{233}_{91}Pa \rightarrow ^{233}_{92}U + \beta$$

5. Clay, Feldspars - Large quantities of two dimentional alumino silicate (Clay) and three dimentional slumino silicate (Feldspars) are available in Sri Lanka. The country has substantial deposits of alluvial clay, ball clay, bloating clay, china clay, clay ochre, kaolin, non bauxite clay and shale. Ceramics industry is the largest mineral-based sector in Sri Lanka. The Government

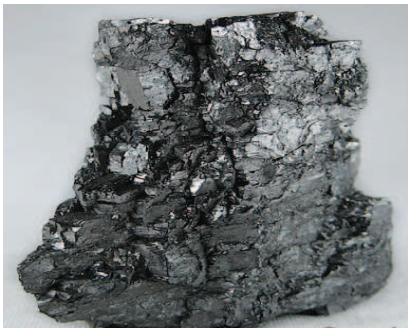
sought to exploit the export market for ceramics used in electronic goods and roof tiles, and to achieve an annual growth rate of 5% for the industry. To boost clay production and identify additional clay reserves, the industry hoped to locate new good-quality feldspar and kaolin deposits. No new ball clay deposits had been identified in the recent past. The clay reserves that were being mined at Boralesgamuwa and Meetiyagoda were expected to run out during the next 2 to 3 years.



Feldspar

6. Graphite -

The mineral graphite is one of the allotropes of carbon. It was named by Abraham Gottlob Werner in 1789 from the Greek γραφειν (graphein): "to draw/write", for its use in pencils, where it is commonly called lead, as distinguished from the actual metallic element lead Some uses of graphite are, Electrodes: *An estimate based on USGS data indicates that graphite electrode consumption was 197,000 tonnes in 2005*. Foundry facing and lubricant *An estimate based on USGS graphite consumption statistics indicates that 2,200 tonnes was used in this fashion in 2005.* Neutron moderator: *Special grades of synthetic graphite also find use as a matrix and neutron moderator within nuclear reactors* Brake linings: *US natural graphite consumption in brake linings was 6,510 tonnes in 2005.*



Graphite

Mica is a generic term applied to a group of rock-forming complex aluminosilicate minerals having a sheet or plate like structure with varying chemical composition and physical properties. Crystals of Mica are characterised by highly perfect basal cleavage in the direction of large surfaces permitting it to split or delaminate into extremely thin and flat films.

7. Quartz, Silica sands & Granite

Major Forms of Silica

Quartzite – This occurs in many parts of the country. The usefulness of this is low due to the presence of impurities such as iron.

Quartz

Vein quartz (Silica quartz)- The vein quartz is known for its high grade (purity i.e. 99.9% SiO_2)

Silica sands- These are found in Madampe, Nattandiya and Marawila areas.

Granite, the durable and elegant material, is not easy to come by as it comes deep within the earth. Its character reflects the creative forces of nature - the patterns of each block of granite tell a story of gigantic pressures, the searing heat of the earth's core, and its violent birth in the volcanic eruptions of bygone millennia. Granite brings grace to the gardens, homes, palaces and temples of Sri Lanka's ancient royalty and add to them a timeless and lasting beauty that has survived for centuries. Sri Lanka has four major types of granite deposits (granite proper, gneissose granite, regmatite and graphic granite) in substantial amounts, suitable for processing into cut and polished stones. The colour, grain structure, hardness and strength of Sri Lankan granite is suitable for the international market.

Granite

$$SiO_2 + 2C \xrightarrow{1{,}700\ ^{o}C} Si + 2CO$$

$$CH_3Cl + Si/Cu \rightarrow (CH_3)_2SiCl_2 + Cu$$

$$SiO_2 + Fe + 2C \rightarrow FeSi + 2CO$$

$$SiO_2 + 3C \longrightarrow SiC + 2CO$$

Chemical principles in the value addition of some Natural Products of Sri Lanka

Each of the following industries has specific chemical principles in the respective manufacturing processes. Chemical principles are also utilized to treat the by products such that the effluents discharged that will conform to the standards in the Table 2.

1. Tea Industry

The shoot tips of the bush of the plant *Camellia sinensis* consisting of the bud and two leaves form the raw material for black tea.

Shoot tips of the plant → manufacturing process → black tea

drying etc. → By products

Tea seed oil, tea saponins, caffeine and spent tea leaves.

Rubber industry

Natural rubber is obtained from the latex of the tree, *Hewa braziliansis*. The principal component of the latex is *cis* polyisoprene.

Rubber latex → sheet rubber, crepe rubber, tyres etc.

By products → Lipids, proteins etc.

Coconut industry

The kernel of the fruit of the tree *Cocos nucifera* is used for the manufacturing process.

Coconut kernel → desiccated coconut, coconut oil,etc.

By products → Coconut water, washings etc.

Other industries

In addition to the above plantation crops, Sri Lanka with its rich biodiversity can have several different industries from natural products. E.g. Ginger is a tuber that is consumed whole as a delicacy, medicine, or spice. It is the rhizome of the plant *Zingiber officinale*. It lends its name to its genus and family (Zingiberaceae).

Young ginger rhizomes → Ginger Limeade, ginger oil etc.

Solid wastes

Prof. H.D. Gunawardhana
Senior Professor in Chemistry
College of Chemical Sciences
Institute of Chemistry Ceylon

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