Module-01: Introduction
Lecture-01: Process Integration - the inherent concepts

Key words:Process Integration, multi-site integration

Last Edited:30.04.12

Often, underlying principles behind technical innovations can be found in the realm of nature. This is also true for process integration as well, if it’s meaning in a broad spectrum is considered. Following examples make it amply clear.

Many of you must have observed that many birds fly in flocks [2, 4]. Geese fly in a variety of formations, ranging from slanted lines topatterns that look like V's, U's, or even W's(Fig.1.1). They have a tendency to fly closeto each other, in the same horizontal plane.Have you ever thought why they fly like this?There are a number of social factors such as reproduction, communication,navigation,protection from predators, etc. However, if only aerodynamic factors are considered for the time being,one apparenttheory is that in coordinated flight flocks such as waterfowl, there's an aerodynamic advantage to flying behind and tothe side of another bird to take advantage of its wingtip vortices. The next time you see ducks or geese flying in a V-formation, you will observe that the lead bird changes its position periodically. This is for the reason that who so ever is on the front takes the maximum drag resistanceof the wind. That is why the leader takes a back position after a while,where wind drag is the lowest. The bird who has taken sufficient rest comes to the front to face the hardship of the flight.Birds also fly in other formations as a strategy for dealing with wind also.

Thus, birds fly in a V-formation(in an integrated form) to help conserve total energy of the flock during migrations [1, 4]. This is an excellent example of flight integration where every bird is benefited.Further, this has been noticed that birds only migrate when there are favorable wind conditions (it takes 40% less energy for birds riding on updrafts than the energy needed for lift if they are flying on their own). In short, to save energy, the winds must be blowing in the direction that the birds want to fly. Birds will usually wait until the most favorable weather conditions then only set off on their journey. This clearly shows that when birds integrate their flying with surrounding winds they are furtherbenefited.

Another example of integration in nature is that fish swim in schools (Fig.1.2). Schools are composed of many fish of the same species moving in more or less harmonious patterns throughout the oceans. A very widespread behavior, schooling, is exhibited by almost 80 percent of the more than 20,000 known fish species during some phase of their life cycle [3]. Aristotle, over 2,400 years ago, observed this behavior in fish.

But why fish swim in schools? Besides a large number of social factors such as safety against predators, there are advantages in terms of energy consumption too. Some species of fish secrete a "slime" that helps in reducing the friction of water over their bodies. Also fishes swim in fairly precise, staggered patterns when traveling in schools and the "to-and-fro" motion of their tails produces tiny currents called "vortices" (swirling motions similar to little whirlpools). Each individual, in theory, can use the tiny whirlpool of its neighbor to assist in reducing the water's friction on its own body.

Another glaringexample of process integration in our society is the concept of Joint Family. It certainly decreases the per member expenditure. Other important example of process integration is “SanjhaChulha” or common burnerwhich had been a tradition of Punjab where many family cook on the same to reduces the use of fossil fuels.Yet another example is cooking of meals in the famous “Jagannath” temple of Puri, Odisha.Jagannath Temple at Puri in India is said to have the largest kitchen in the world. The kitchen prepares food for 100,000 people on a festival day and for about 25,000 on a normal day. The unique feature of cooking in this temple is that, clay pots are placed in a special earthen oven, five in numbers, one on the top of another thereby saving a lot of energy in cooking. A similar principle used in multi-effect evaporation system. The above tradition is prevalent since 11th century.

Even the concept of Integration is visible in microorganisms. This is known as symbiosis. It is a relationship between individuals of different species where both individuals derive a benefit from living together.One of the most spectacular example of symbiosis is between “siboglinidtube worms” and “symbiotic bacteria” that live at hydrothermal vents and cold seeps. The worm has no digestive tract and is wholly reliant on its internal symbionts for nutrition. The bacteria oxidize either hydrogen sulfide or methane which the host supplies to them.

A considerable number of examples can be found in nature which shows that an integrated process takes less energy to perform an assigned task. But the question is how to use this concept in process industry?

The examples given below use the concepts of process integration in process industry examples. One such example of integration in process industry (Fig.1.3) can be seen in the sixteenth century technology of gold retrieval as described below [6]:

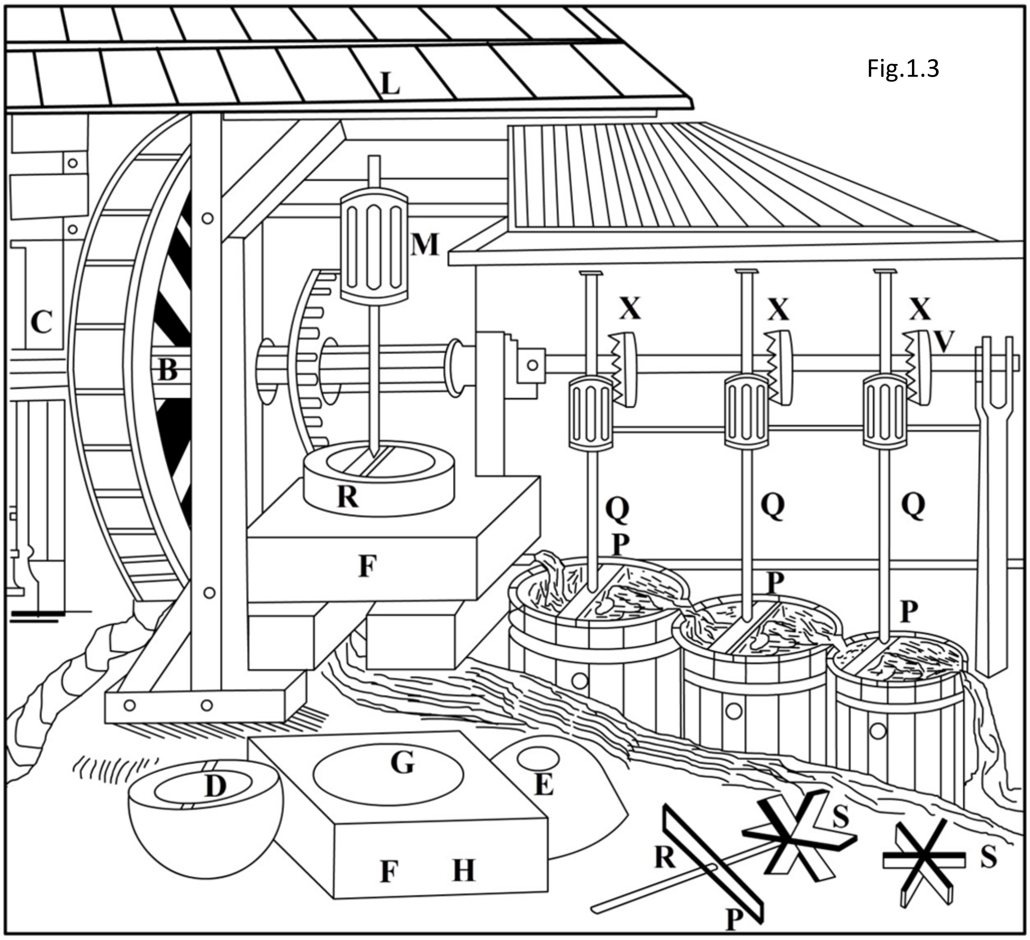
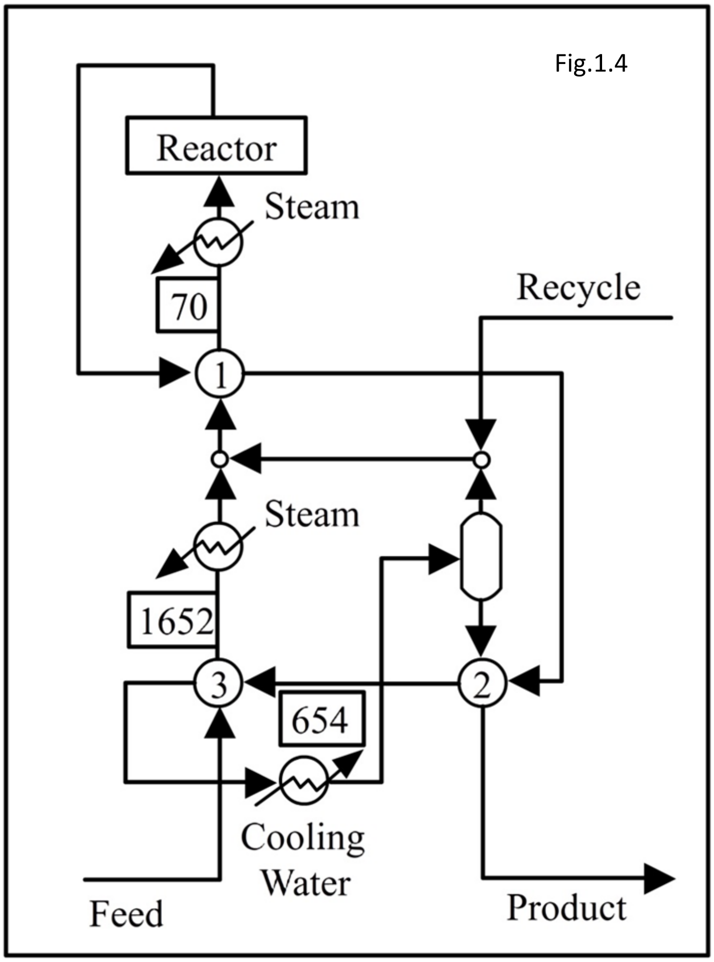


Fig.1.3

The technology is very simple. The ore is crushed by the stamp, “C,” ground in the mill, “F,” andmixed with mercury in vessels “O.” Gold is extracted from the ore by mercury andis later separated from it by pressing the mixture through a leather or cloth filterbag (not shown in the drawing).

Taking a closer look at the woodcut, one noticesthat the stamp, the mill and the stirrers for mixing the ore with mercury are alldriven by the same water wheel, “A,” via the common axle, “B,” and a number ofvarious gears. In the language of the 21st century, one could say, “A marvelous example of a green, energy-based, highly integrated processing plant.

As a second example let us consider a front end specialty chemical process illustrated in the Fig.1.4 below [7]:



The process uses six heat transfer units (2 heaters, 1 cooler and 3 heat exchanger units and has an energy requirement of 1722 kW of heating and 654 kW of cooling. From the first appearance it appears to be thermally efficient whereas it is not so. So, what is wrong with it?

The answer is that it lacks effective integration. This will become clear from the figure 1.5 shown below:

This configuration (Fig.1.5) uses only four heat transfer units and the utility heating load is reduced by around 40 % (1068 kW) with cooling no longer required. The design is safe and operable as the earlier one. It is simply better, as it has most effective energy integration.

Another inspiringexample[8] of process integration is shown in Fig.1.6. The figure shows a coal pyrolysis process. The main products of which are different hydrocarbon cuts. Benzene obtained from pyrolysis is further processed in a hydrogenation reactor to produce cyclohexane. A hydrogen-rich gas is produced from the cyclohexane reactor and is currently flared.

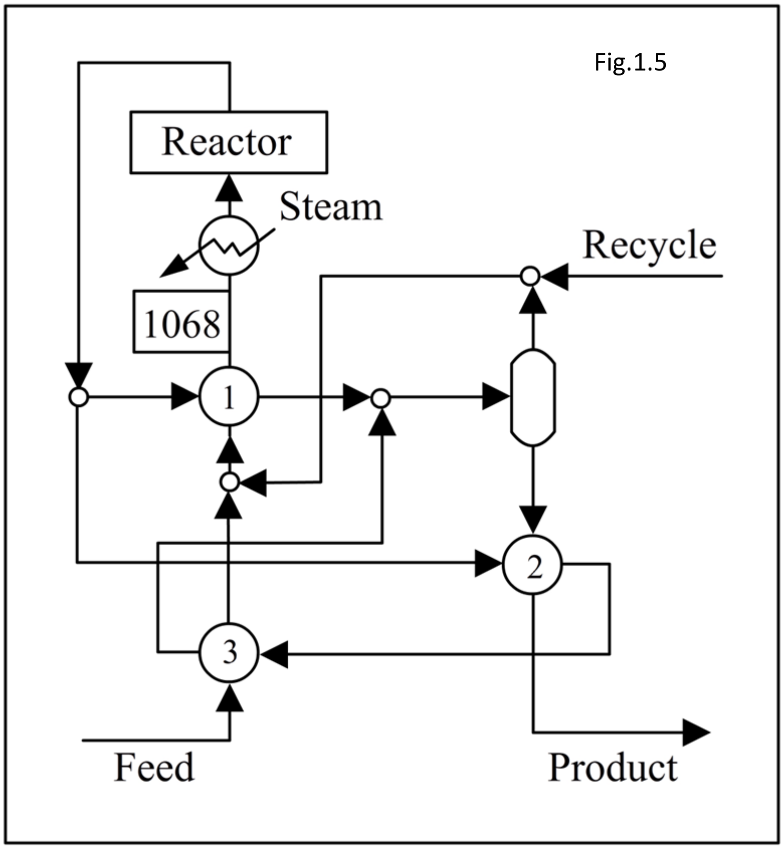


Fig.1.5

Further the process demands that, medium and heavy distillates contain objectionable materials (primarily sulfur, but also nitrogen, oxygen, halides) should be removed and unsaturated hydrocarbons (e.g. olefins and gum-forming unstable di-olefins) should be converted to paraffins.

One way of addressing this problem is to establish hydro treating and hydro desulfurization units requiring fresh hydrogen to remove the objectionable material and to stabilize olefins and di-olefins as shown in the Fig.1. 6.

But, the drawback of this process is that there is no integration of mass. At one side, fresh hydrogen is being purchased and used in hydro treating and desulfurization and on the other side; hydrogen produced from benzene dehydrogenation is flared. Therefore, to improve the economics of the process, process integration is needed in this case to conserve the resources.

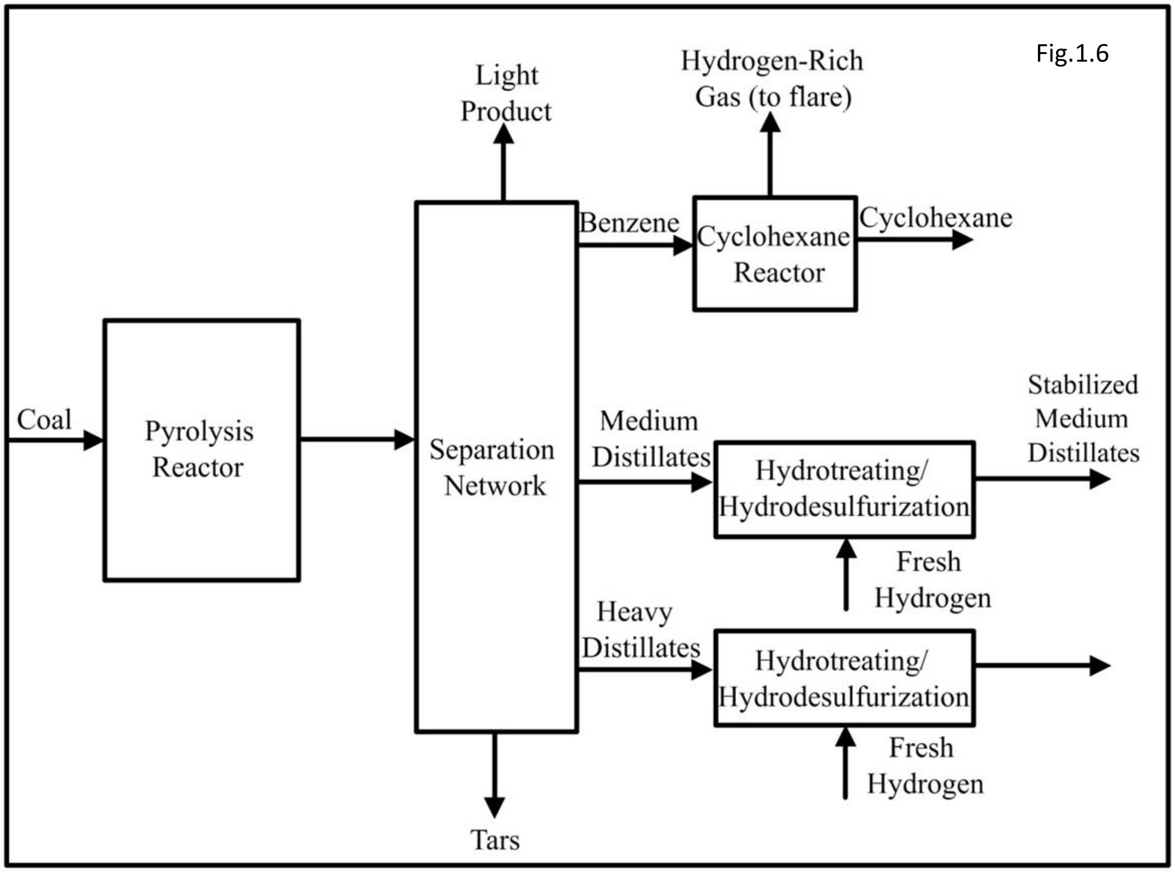


Fig.1.6

In addition to integration with in a process, we often come across examples where significant benefits have been obtained from integration between different processes.One such example of multi-site integration where sites operating different processes are linked indirectly through utilities is shown below [7] in Fig.1.7: In this scheme exhaust steam of power plant is used in Processes A,B and C.

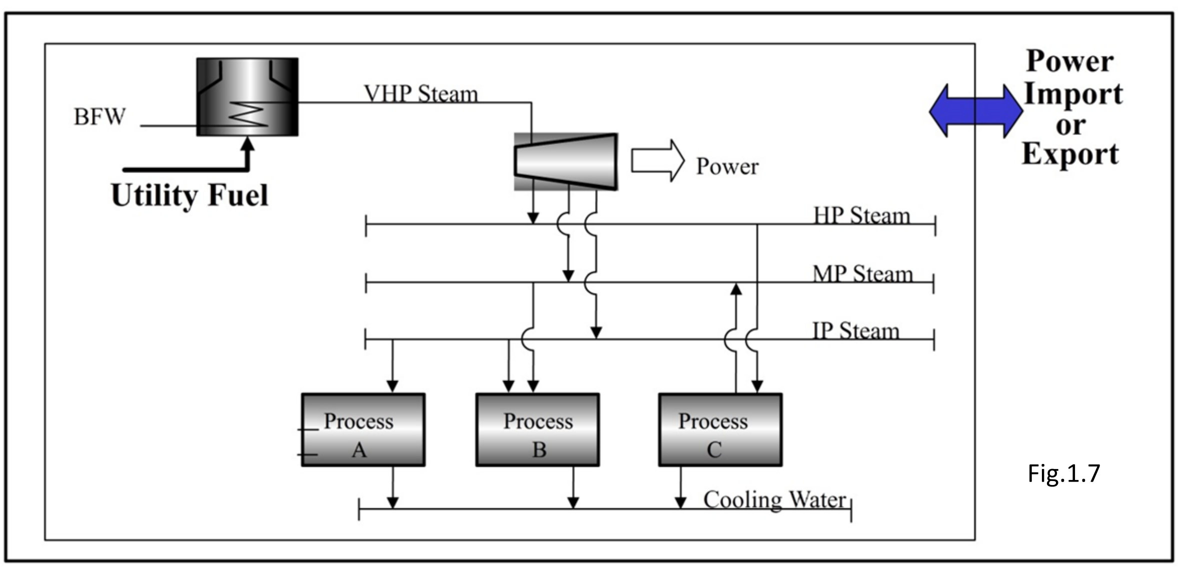


Fig.1.7

Another example of multi process integration is the integration between steel plant and oil refining plant. In this case, coke oven gas is fed to hydrogen generation unit to increase its production. In this way, the otherwise waste gas is used for producing useful chemicals like gasoline and gas oil. The detailed process is shown in Fig. 1.8 below [11]:

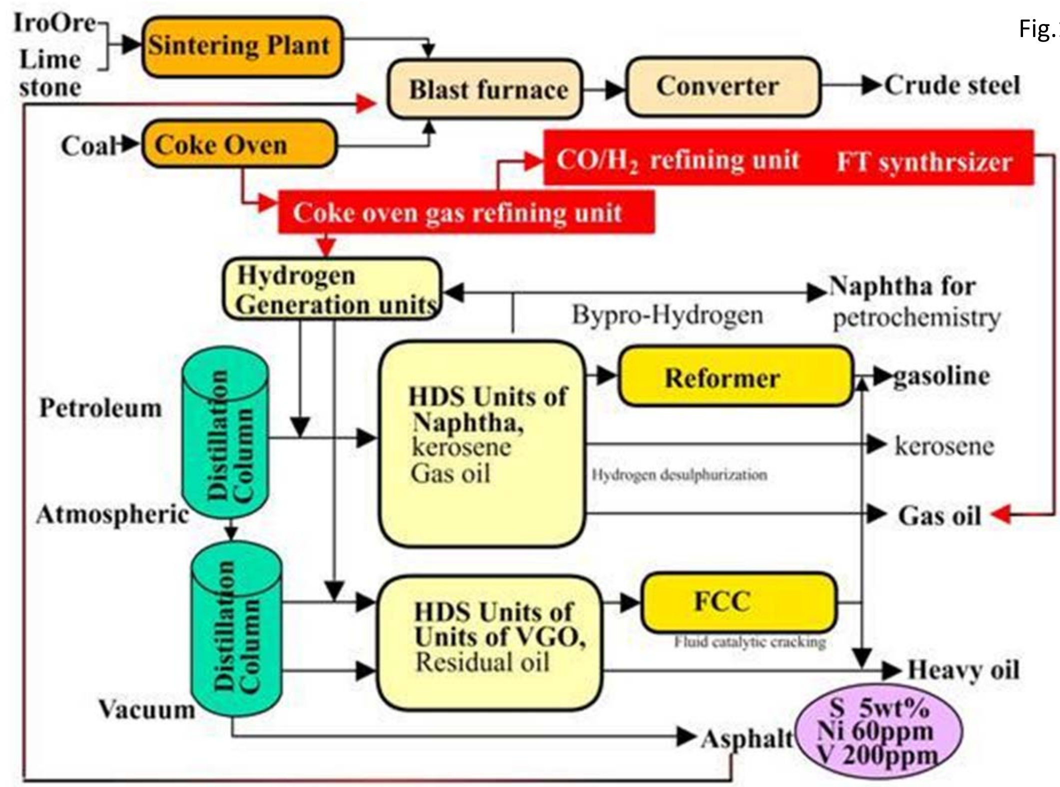


Fig.1.8

After establishing the fact that process integration will certainly help in reducing the utility and material consumption of process industry, now let us see what the extent of energy loss from different industries is? Fig. 1.9 shows the extent of energy loss from different industries[10] which clearly offers necessary impetus to save energy losses.

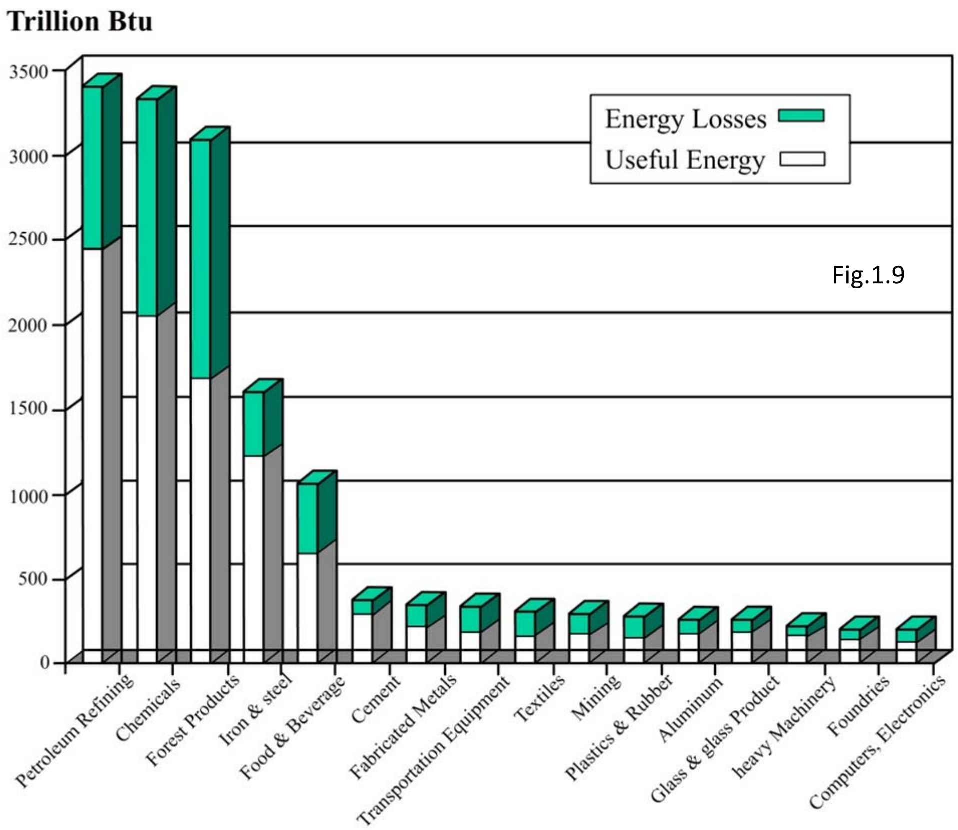


Fig.1.9

After observing clearly the benefits of process integration in process industries, let us examine potential benefits [9] which can be obtained from the application of process integration in different industriesas reported in figure1.10below:

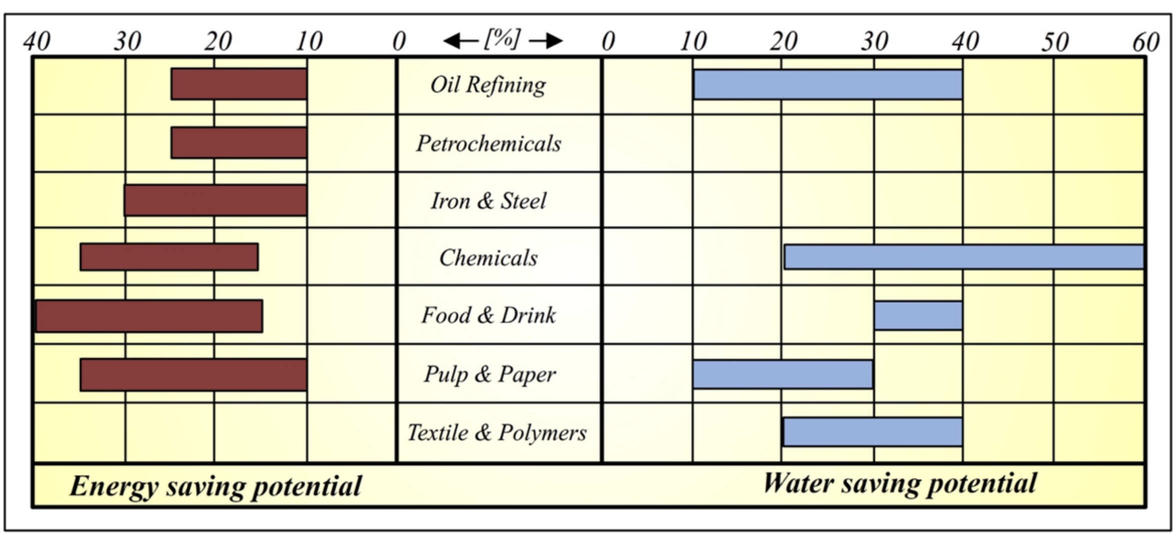


Fig.1.10

From the above examples, which were drawn from nature as well as existing industries, it is now amply clear that process integration helps industry to conserve energy and material. Conceptually **Process integration** is a term in chemical engineering which means a holistic approach to process design which considers the interactions between different unit operations from the outset, rather than optimizing them separately. This can also be called *integrated process design* or *process synthesis.* Smith (2005) has described the approach well [5].

Now the question is whether there is a systematic analysis technique which will guide us step by step to apply process integration principles in industries. The answer is yes.

References:

1. http://birding.about.com/library/weekly/aa032898.htm
2. http://www.squidoo.com/why-birds-fly-in-v-formation
3. http://seagrant.gso.uri.edu/factsheets/schooling.html
4. http://www.aerospaceweb.org/question/nature/q0237.shtml
5. Smith, R. (2005). Chemical Process Design and Integration. John Wiley and Sons. ISBN 0471486809
6. FlndrzejFtankiewicz, Jacob fl. Moulijn, Re-engineering the chemical processing plant, process intensification, Marcel Dekkher, 2004.
7. Ian C Kemp, Pinch Analysis and process integration, a user guide on process integration for effective use of energy, $IChem^E$, Elsevier Limited, 2007.
8. Mahmoud M. El-Halwagi, Process Integration, Process Systems Engineering, Volume 7, Elsevier Inc., 2006.
9. P. Raskovic, Process integration approach for energy saving and pollution prevention in industrial plants, Faculty of Technology Engineering, Leskovac, Serbia, 2007.
10. http://texasiof.ces.utexas.edu/PDF/Presentations/RoundTable_0906.pdf
11. IEA international workshop, Pinch technology for energy conservation activities, NEDO technology development organization, 19^{th} January, 2004.

Last Edited:16.11.11