Process Integration
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Module - 1
Introduction
Lecture - 1
Process Integration, Methods and Area of Application

Welcome to the lecture series on Process Integration. This is module-1 and lecture-1. The topic of the lecture is process integration methods and application. In this lecture, I will introduce the concept of process integration and while doing, so I shall derive it from the nature.

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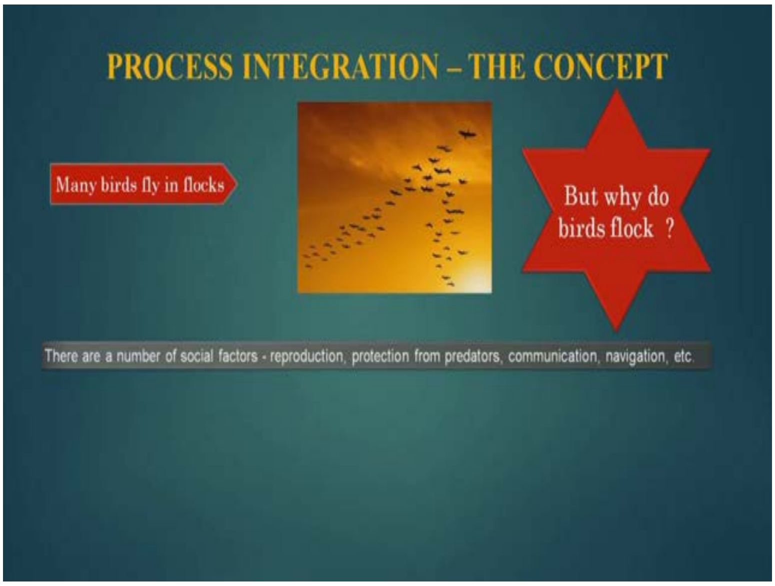

Let us see natural phenomena which takes place in nature and the example is that how the birds fly? Many birds fly in flocks as shown in the picture, but why do birds flock? There are number of social factors for this, which includes reproduction, protection from predators, communication and navigation, etcetera.

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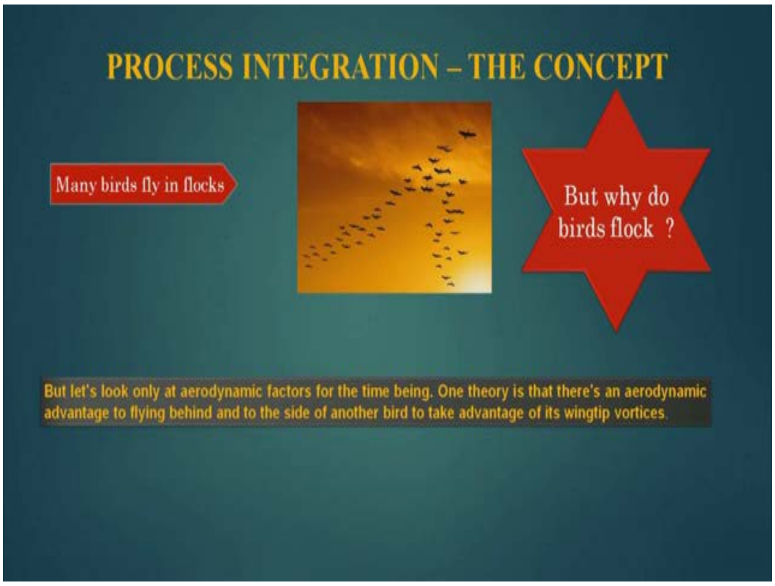

But let us look at only at the aero dynamic factors for the time being. One theory is that there is an aerodynamic advantage to flying behind and to the side of another bird to take advantages of its wingtip vortices.

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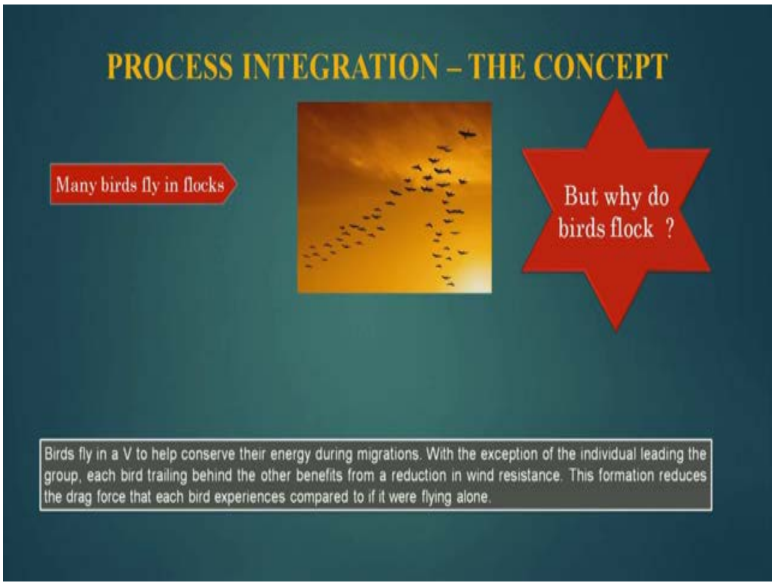

Birds fly in a V-shaped to help conserve their energy during migration with the exception of the individual leading the group. Each bird trailing behind the other benefits from a reduction in wind resistance, this formation reduces the drag force that each bird experiences compared to if it were flying alone. So, it clearly tells that if birds are flying in flocks. They conserve energy or I can say that per unit consumption of energy; that means, consumption of energy per bird in a flock is less and this is for flying.

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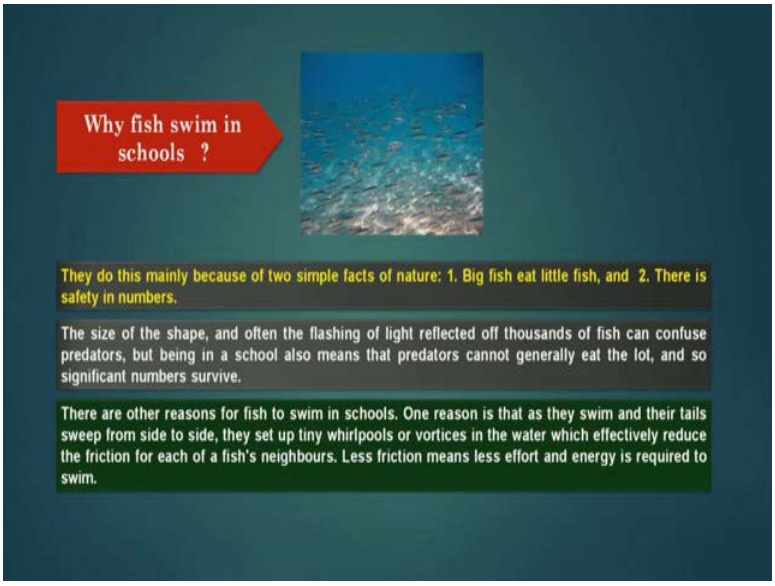

The same phenomena; we can see in the nature when the fish swim. So, let us take the case of the fish. Fish swim in schools, why this happens? They do this mainly because of two simple facts of nature; the one is big fish eat little fish and two there is safety in numbers. The size of the shape and often the flashing of light reflected off thousands of the fish can confuse the predators, but being in a school also means that predators cannot generally eat the lot. So, significant numbers survive, but this are not the technical reasons for it.

So, let us see the technical reason why the fish swim in school? There are other reasons for fish to swim in schools. One reason is that they swim and their tails sweep from side to side. They set up tiny whirlpools or vortices in the water which effectively reduces the friction for each of a fish's neighbors. Less friction means less effort and energy is reduced in swimming that means the techniques which these animals or the birds and fishes apply in nature. There is an inherent concept of integration in them. So, where then integrate their flying styles integrate their swimming styles they consume less energy. This is also other examples through other examples we can show this also like joint family.

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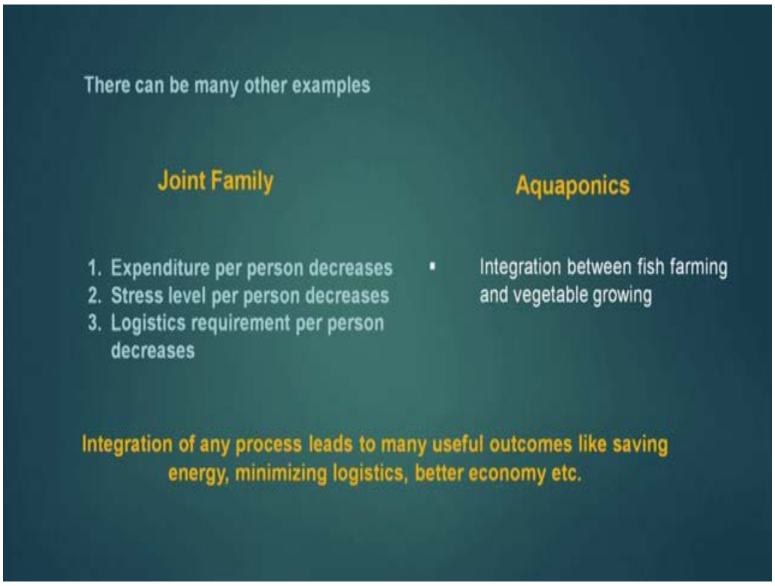

If we take a joint family then we find that expenditure per person decreases in a joint family, stress level per person also decreases in a joint family and logistics requirement per person also decreases. So, joint family which is an integration of individuals due to this integration we see that these are the benefit that is expenditure decreases, stress level decreases and logistic requirements also decreases. The latest concepts, which are aquaponics. They are integrate fish farming with vegetable growing. The fishes help the vegetable to grow and vegetable also help fishes in terms of their food. So, in the nature there is the lot of concepts which are available. So, that integration helps each other ; A conclusion we can draw from the nature that integration of any process leads to many useful out comes like saving energy, minimizing logistics and better economy.

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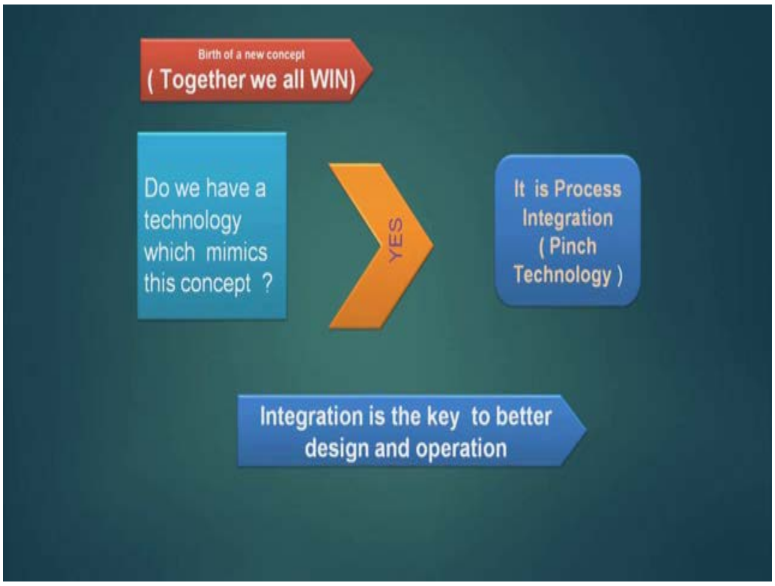

Now the question is that do we have a technology, which mimics this concept, because this we have learned that together we all win and this is a new concept and which is available in the nature can we translate this concept to our industry. So, the question is do we have a technology which mimics this concept the answer is yes, it is process integration or in other word, we can say pinch technology which mimics this. So, the integration is the key to better design and operation. Let us slowly this concept will unfold, and we will see that how we bring out this betterment in design and operation through process integration.

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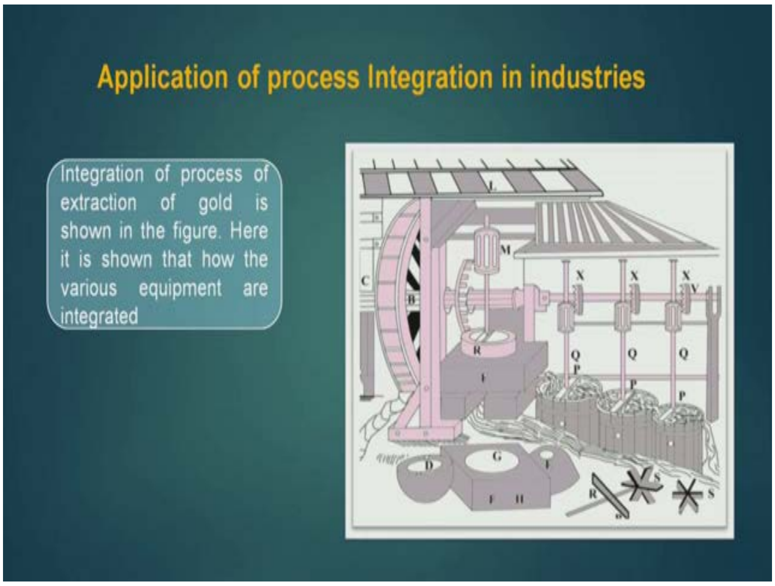

This is an application of process integration in the industries. In the older days, when gold is to be extracted by amalgamation process using mercury, we see that this turning and other things are integrated with water fluid. So, by integrating a lot of work can be done simultaneously this is being used in the old industries for extraction of gold.

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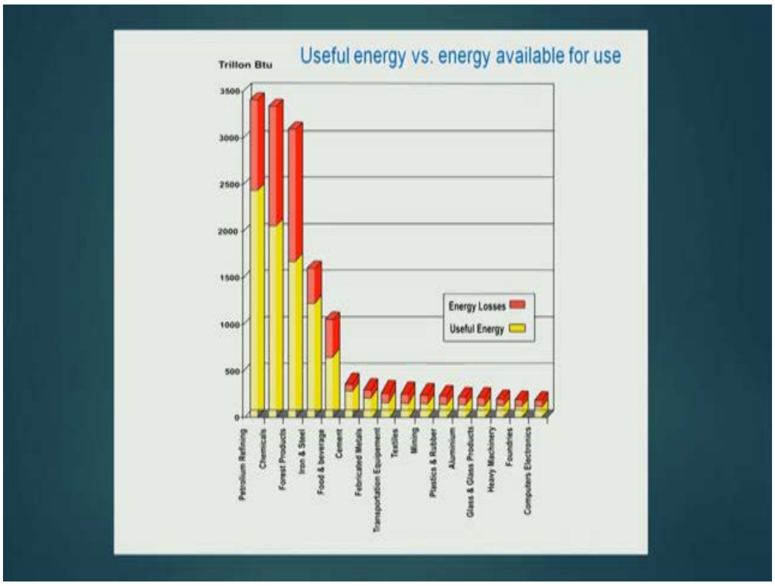

Now if you see the energy scenario of the industry that what is the energy available to the industry, how much energy available to the industry and how much useful energy out of the energy available is used in the industry. So, rate part of this craft shows that the every industry is losing a large amount of energy when utilizing the energy available to it. Now the question is can we decrease this energy loss from the industry through design or through processes integration.

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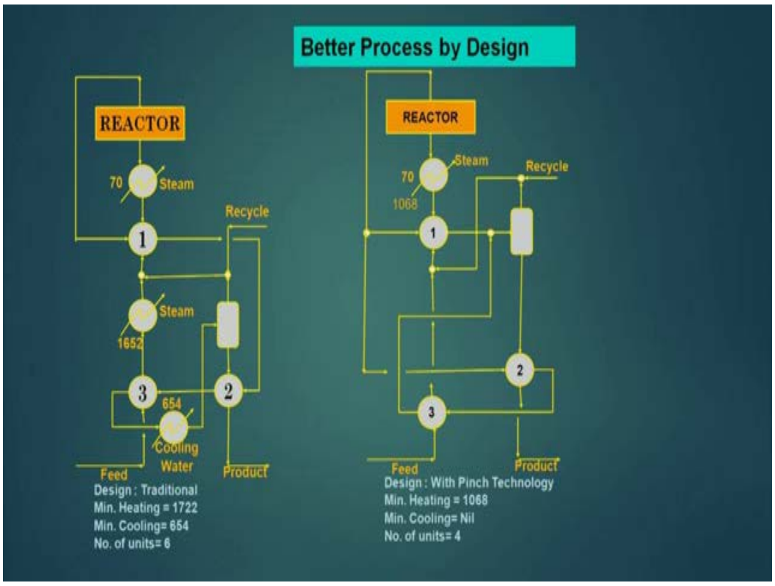

Now from this example which is been there in the screen. Let us see that how a better design can be given through process integration. We see the left hand side picture there we see that the whole process which as a reactor, a say flash drum and there are few heaters. If we take this traditional design the minimum heating requirement was 1722 units. It has three heat exchangers, two heaters and one cooler and minimum cooling requirement was 654 units and number of units was 6. So, the traditional design when on this design the concept of process integration was applied then the design was simplified and now it requires 1068 units of minimum heating.

A lot of heating requirement has been decreased almost about 740 odd units of heating has been decreased and cooling has been made equal to 0, that means in the improved design we do not need cooling utility that is cold water; that means, a complete area of the industry which handles the coolant or cooling requirement or cooling utilities now of; that means, we do not need a cooling tower even.

So, this is a big achievement and big reduction in the cost further the number of units required is four; that means, we are able to save the utilities we are able to save the number of units which are required for the operation of this process and this we have not compromised anywhere; that means, the output is the same the steam stream temperatures of the exits temperatures of this streams are the same, reaction inlet temperatures and outlet temperature of the reactor is the same.

Everything remains same, but the process is oriented in such a way designed in such a way using the integration principles that it gives you a lot of saving. Now the question is can this design procedure the process integration which is based on the thermo dynamics can help us to save capital cost and energy for this.

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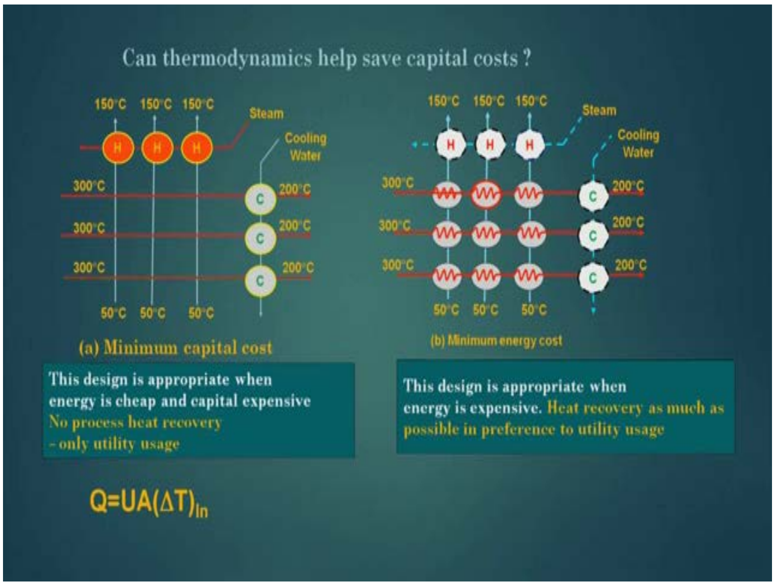

We go to the figure the left hand side figure here there are three hot streams which has inlet temperature of 300 degree centigrade's, out let temperature of 200 degree centigrade's and there are three cold streams which has inlet temperature as 50 degree centigrade and out let temperature as 150 degree centigrade. Now, we know from the design that Q is equal to UA delta T that means, if I can increase the delta T in if U remains constant then A decreases. So, if I heat the cold streams using heat which is at the highest temperature; that means, more than 150 degree centigrade and if the cooling water is at the lowest temperature may be 35 degree centigrade, 30 degree centigrade then the delta T available for this design is very high and if the delta T in is high then area will be less.

So, this is a concept in this design we see that we will see that this concept does not work perfectly. So, I expect that this design will give me the minimum capital cost as my area will be minimum. This type of design is appropriate when energy is cheap and the capital is expensive because in this design there is no concept of heat recovery and I am using only the utility to meet my targets. Now let us take this second case which is in the right hand side here. Every cold stream is exchanging heat with every hot stream and there is no heater present and there is no cooler present, because cooler and heaters are shown in dotted lines, the stream and cooling water is also shown in dotted lines.

So, these are absent in this design; now here I am using the full concept of process heat recovery this design is appropriate when energy is expensive. Heat recovery as much as possible is turn in this design and no utility is used. So, these are two extreme ends of design in one end I am utilizing the heat recovery completely and in other i am not utilizing it. So, let us compare these two things, because I expect that in the case b my fixed cost will be very high as I am saving energy through passes heat recovery now the question is this purpose is correct.

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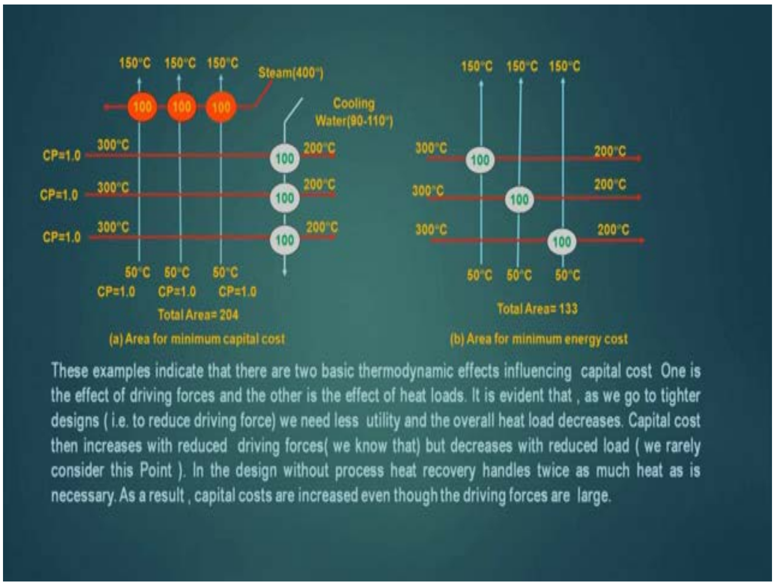

So, if we quantitavely analyze this two concepts then for a where I am using the utilities completely to satisfy the cold streams as well as hot streams. The area requirement is 204 units. Now, in the cost case b when I am using the heat exchange completely. I am not using any utility cost. I am using three heat exchangers to exchange the heat my area requirement is only 133. Now this is a result which is completely against our earlier third process the area has decreased; that means, the fixed cost has degrees in the case b as well as I am saving a lot of utility, because I am going for complete exchange of heat in the network.

So, in both case I am gaining in capital case capital cost as well as the running cost, but the question why this has happened this may be against the general thinking general rules. Now let us examine this these examples indicate that there are two basic thermodynamic effects influencing capital cost, one is the effect of driving force that is delta T which we have seen in the equation Q is equal to UA delta T im, but the second effect the other is the effect of heat flow this we have not considered in our design it is evident that as we go to tighter designs; that means, reducing the driving force we need less utility and the overall heat load decreases and these fact was not considered in the earlier analysis.

Capital cost then increases with reduce driving force that we know from Q is equal to U A delta T, but decreases with reduce load we really consider this point and what has happen in this design. In the design without process heat recovery handles twice as much heat as is necessary and hence in part a of the design the total area requirement is 204 because it is handling twice the amount of heat almost as in the case of b in the design without process heat recovery. It handles twice as much heat as is necessary as a result capital cost are increased even though the driving force are large.

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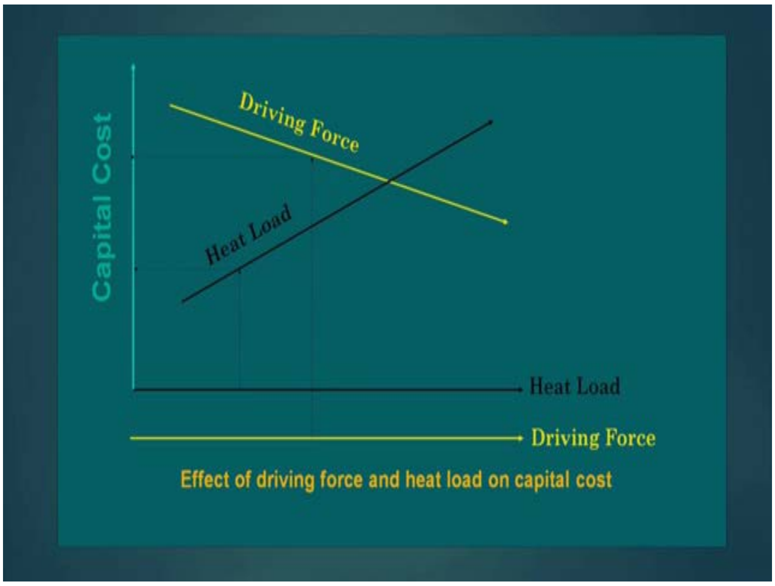

Now what we have observed that when we are increasing the driving force of heat exchanger network. The capital cost decreases and this is given by this line. So, when we are increasing the driving force the capital cost decreases; however, when we are increasing the driving force the heat load increases. This is the new fact which has come out and hence we saw that even decreasing the increasing the driving force is not decreasing the area of heat exchange that is fix cost as much as we were expecting, because it increases the heat load. So, we cannot apply exactly the formula Q is equal to UA delta T because when we are changing the delta T or increasing the delta T Q also increasing Q is equal to U A delta T is applied in those areas when changing delta T Q is not changing.

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Now, if it's if you see these scenarios of successive plants with time then we find that if this is the minimum energy requirement for an industry. We find that the old processes the design was something somewhere here. So, there was a large gap between the minimum energy consumption and the energy the industry used to consume with the time this gap is decreasing; this is with conventional design. So, if I am going for design through traditional methods or conventional methods this is the graph I am following where this gap the energy consumption gap and minimum energy gap is decreasing.

However, if we use a design which is based on process integration or thermal integration. We will formulate a design which is somewhere here which is very close to the minimum. So, if we are improving our design of thermal integration using process integration principles we will be able to give better designs which will be near to the minimum energy consumption.

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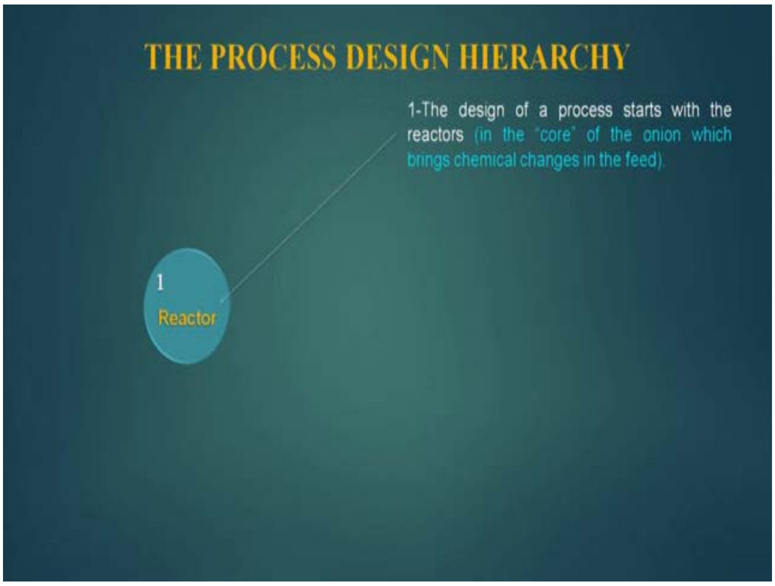

Now if you see the process design of a chemical industry then a chemical industry is converting raw material to the products using a chemical change and this chemical change is brought about using a reactor. So, the central portion of a chemical industry is a reactor. So, the design of a process starts with the reactor in the core of this onion diagram which brings chemical changes in the field. Then, when I am going for a reactor if I converting a to b the b will not only be formed with this c and d will also be formed which are bi products.

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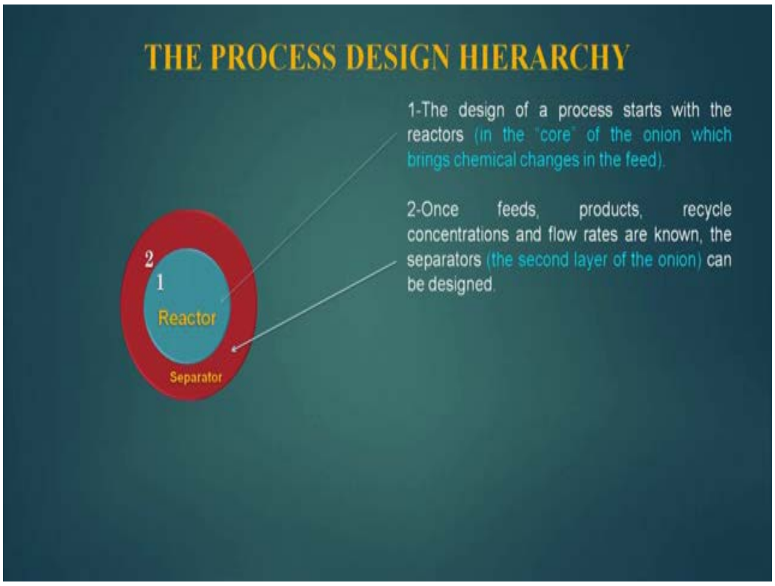

So, we need a separation processes for this. So, my second layer is once feed products and recycle concentrations and flow rates are known then we have to design the separators the second layer, because without separating the bi products from the product i cannot sell the product in the market.

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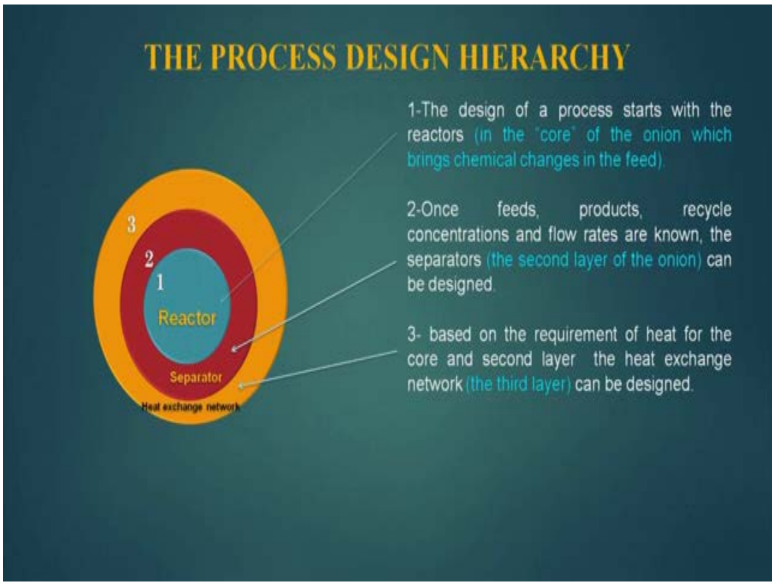

So, my second layer is a separation layer then I have a third layer which is called heat exchanger layer, because for the separation we need energy like for example, in a distillation column two liquid components are separated with heat energy. So, based on the requirement of heat for the core and the second layer the heat exchange network the third layer can be designed.

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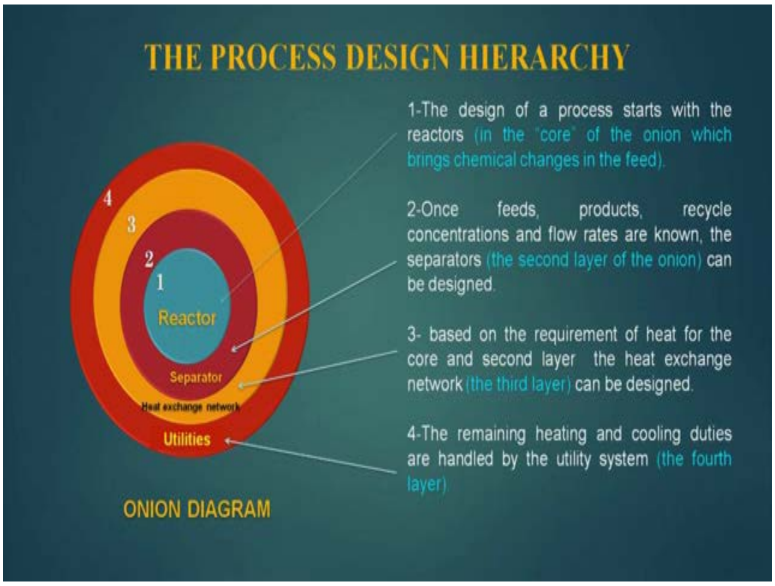

The fourth layer which is the utility layer. So, the remaining heating and cooling duties are handled by the utilities system the fourth layer. So, a chemical industry can be visualized as an onion having many layers and that's why this diagram is called an onion diagram. Now the process integration the concept of process integration can be used in all the four layers we can use it for reactors, we can use it for separators and the separated it becomes mass exchange mass integration for here. It becomes heat integrations and so on the whole diagram. The onion diagram we can use our process integration principle.

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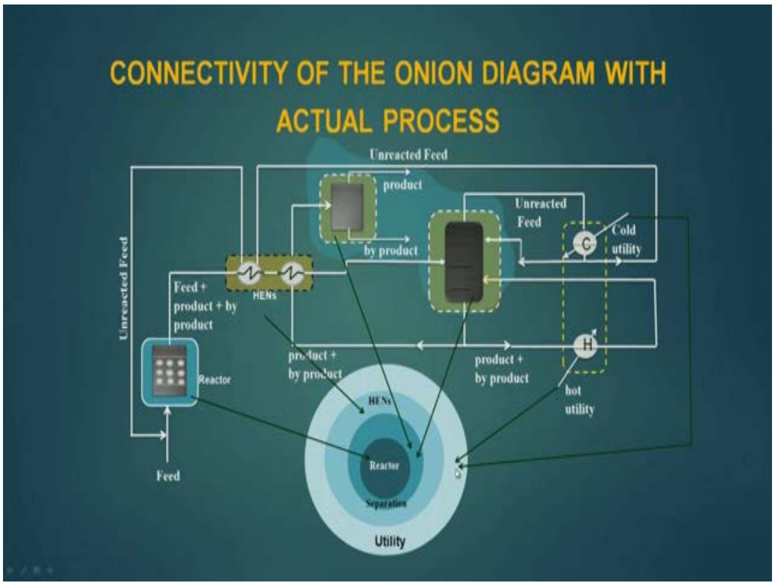

Now, let us use this onion diagram and connect to a process flow diagram this is the process flow diagram here. The feed is entering this is a reactor. So, in the reactor I am getting a output which contains feed un reacted feed and by products this are at higher temperature this exchanges feed with the incoming feed and then the products which are the product plus by products it goes to this product which is the feed plus product plus by products goes to a separation system.

At the bottom of the separation system I get product and by product and the un reacted feed goes here, which exchanges it with a cold utility comes here and a part goes from here and it exchanges heat here and then it is again fed to the reactor .So, the bottom product from this say distillation column goes here exchanges heat; that means, it is heated up and then it is goes as feed through this distillation column. Then part of this by product goes to a separator which may be a flash term where I am getting product and by product. So, these are two mass exchange equipments which are three mass exchanges.

So, they fall to the layer of separation, this is reactor it falls to the reactor layer, which is in the core. And these are heat exchangers, they fall to the HENs layer heat exchanger network layer, and then these are heater and coolers where they also fall to the HEN layer, but here I have shown that the cold utility and hot utility which is being used here fall to the utility layer. So, here we have taken a small PFD and we have shown that how the part of this pfd are related to the onion diagram.

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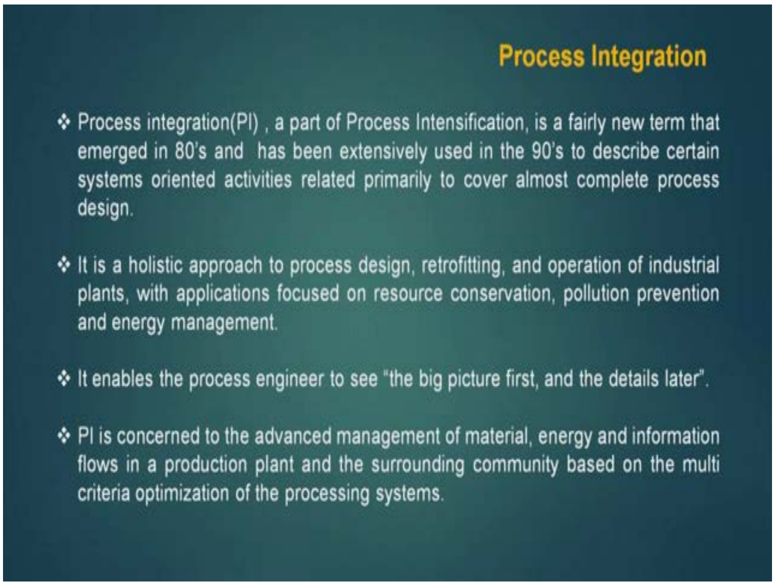

Now let see what process integration is let us see some definitions. Processes integration a part of process intensification is a fairly new term that emerged in 80's and has been extensively used in the 90's to describe certain systems oriented activities related primary to cover almost complete process design.

It is a holistic approach to processes design retrofitting and operation of industrial plants with applications focused on resource conservation pollution prevention and energy management. It enables the process engineer to see the big picture first and the details later. In the process integration we draw the big picture first we believe that if the big picture is correct then we should go for the details later on that means, we can analysis the details later on the first aim is to create the big picture first and this big picture is created using process of integration. Process integration is concerned to the advanced management of material energy and information flows in a production plant and the surrounding community based on the multi criteria optimization of the processing systems.

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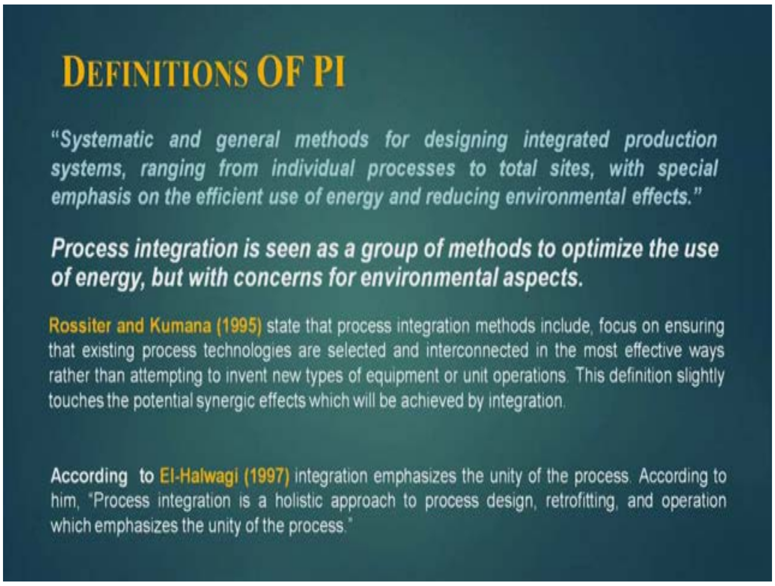

Now if you see the definition of PI there are many definitions which were given to PI by different people one definition is it is a systematic and general methods for designing integrated production systems ranging from individual processes to total sites with special emphasis on the efficient use of energy and reducing environmental effects.

Other definition is process integration is seen as a group of methods to optimize the use of energy, but with concerns for environmental aspects.

Rossiter and kumana in 1995 gives this definition state that process integration methods include focus on ensuring that existing process technologies are selected and interconnected in the most effective ways rather than attempting to invent new type of equipment or unit operation. This definitions slightly touches the potential synergic effects which will be achieved by integration according to the ei-halwagi in 1997 integration emphasizes the unity of the process according to him. Process integration is a holistic approach to process design retrofitting and operation which emphasizes the unity of the process.

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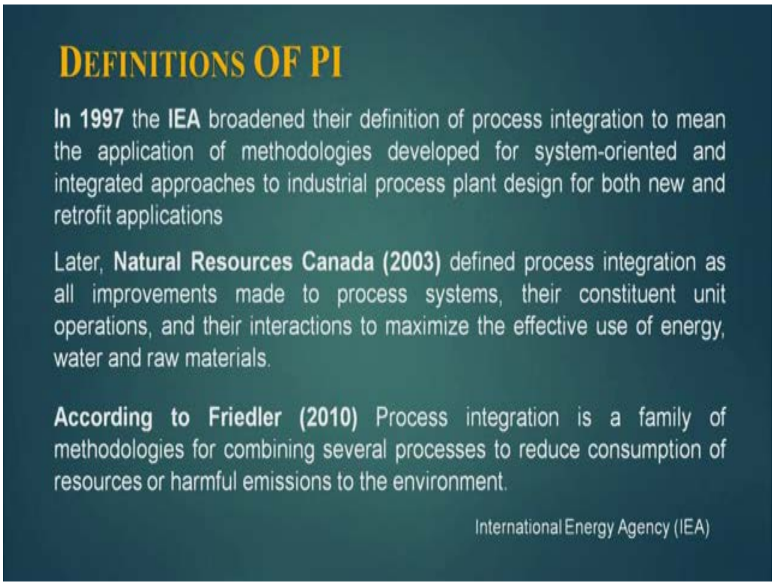

Other definitions in 1997 the IEA which is international energy agency broadened the definition of process integration to mean the application of methodologies developed for system oriented and integrated approaches to industrial process plants designed for both new and retrofit applications. Later natural resource Canada in 2003 defined process integration as all improvement made to process systems their constituent unit operations and their interaction to maximize the effective use of energy water and raw material. According to the fielder in 2010 process integration as been defined as is a family of methodologies for combining several processes to reduce consumption of resources or harmful emission to the environment. So, what we saw in this definitions. The concept of integration is that the concept of integration of equipment why to decrease the energy required for the process and to stop or to decrease the harmful emissions.

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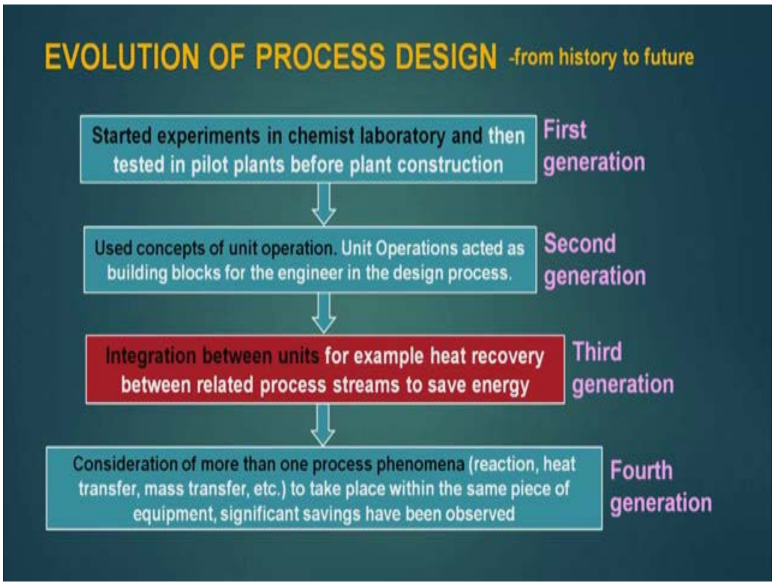

Now if you see the evolution of process design from history to the future. In the first generation what we used to do the process design used to be start with experiments in chemist laboratory and then tested in pilot plants before plant construction then came. The second generation here we use the concept of unit operation and the unit operation acted as building blocks for the engineers in the design process.

Now in the third generation of process design the concept of integration came into picture. So, the integration between units came into picture for example, heat recovery between related process streams to save energy. And in the fourth generation, we considered more than one process phenomena taking place in a equipment that is reaction heat transfer mass transfer etcetera to take place within the same piece of equipment. And doing this a significant savings can be observed it is a part of process intensification which is a fourth generation process design concept.

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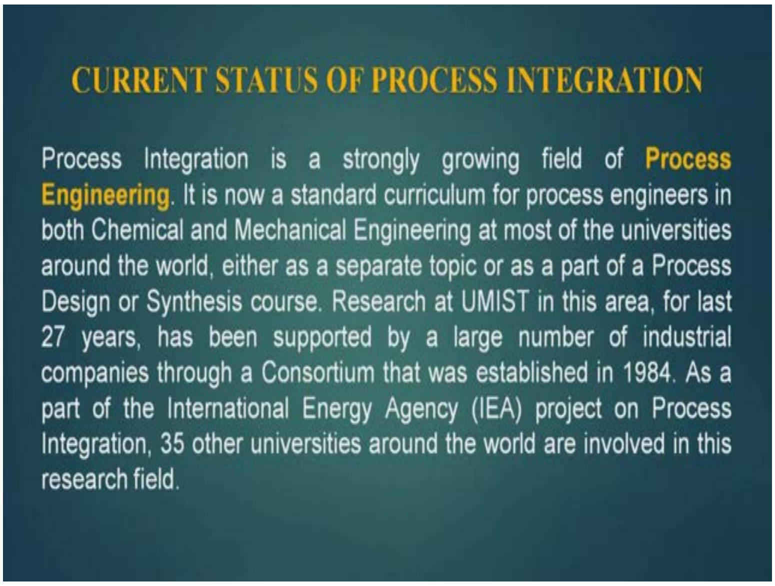

Now, we see the current status of process integration is a strongly growing field of process engineering. It is now a standard curriculum for process engineers in both chemical and mechanical engineering at a most of the universities around the world, either as a separate topic or as a part of a process design or synthesis course. Research at UMIST in this area for last 27 years or. So, has been supported by a large number of industrial companies through a consortium that was established in 1984 as a part of the international energy agency. A project on process integration 35 other universities around the world are involved in this research field. So, this is shows you the current status of the process integration how much work is in being carried out in different universities of this world.

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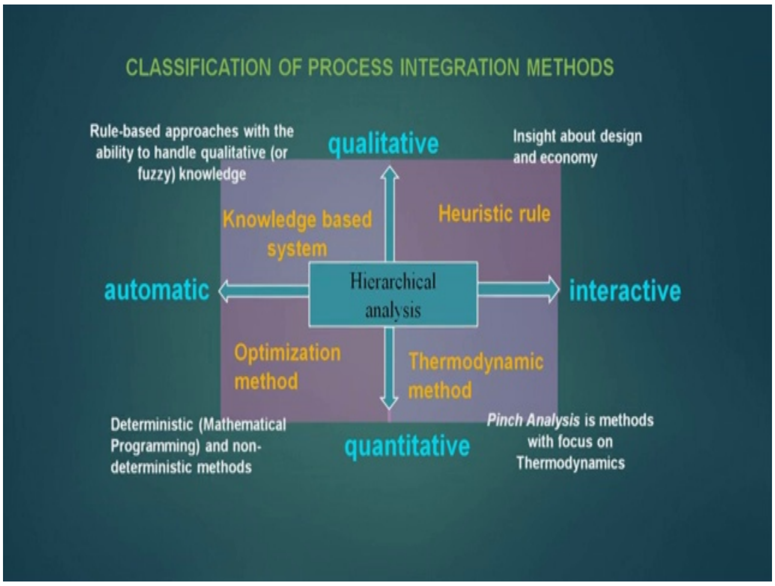

Now let us see what the classification of process integration methods is. This is the hierarchical analysis it can be divided into four quadrants the first quadrant is interactive and qualitative, the second is qualitative and automatic third quadrant is automatic and quantitative and fourth is quantitative and interactive.

Now, if you see the first quadrant in the first quadrant we use heuristic rules and this gives insight about the design and economy. Now if we see the second quadrant here we use the knowledge based systems these are the rule based approaches with the ability to handle qualitative or fuzzy knowledge in the third quadrant, we use the optimization method. So, these are the methods for which can use for process integration proposes. So, in the optimization method we used deterministic mathematical programming and non deterministic methods and the fourth one which is quantitative and interactive here. we use the thermodynamic methods and the pinch analysis has becomes very famous and based on thermodynamic method is used with focus on thermo dynamics.

So, how the process integration is tackled is shown by these four quadrants and each quadrant can handle the process integration processes, but the pinch technology area which falls in the fourth quadrant is this scope of this lecture series.

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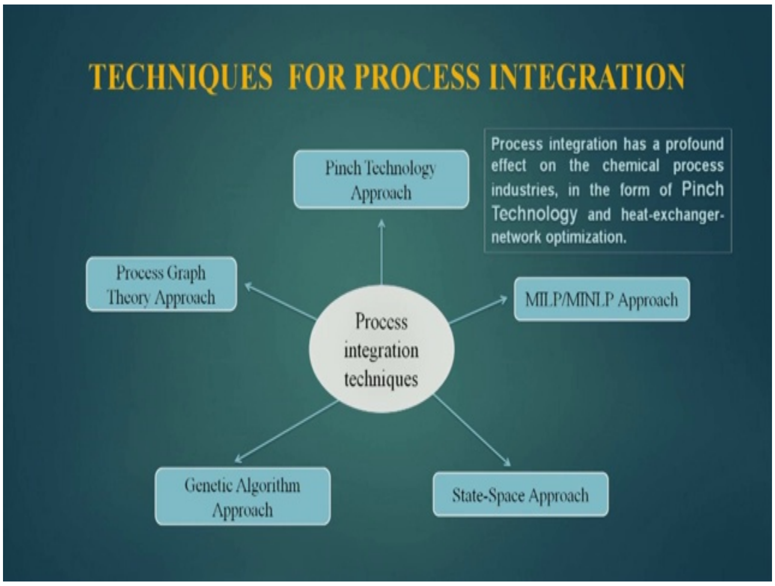

Now the techniques for Process Integration; let us see what different techniques which are available for process integration. The pinch technology approach which we have seen in the fourth quadrant can solve it process graph theory can also be used for process integration purposes genetic algorithm approach which is basically optimization technique can be used for process integration state space approach can also be used for process integration and MILP, MINLP approaches can also be used for process integration.

So, the process integration has a profound effect on the chemical process industries in the form of pinch technology and heat exchanger network optimization which; obviously, fall we have seen in the fourth quadrant.

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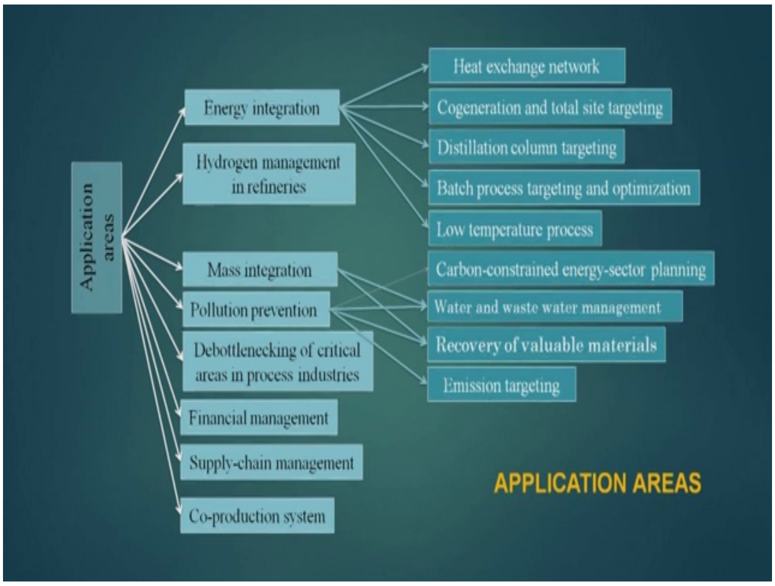

Now as this method is becoming very popular, it can be used for similar applications. If you see the applications we see here the energy integration, we can use it for heat exchanger network design for cogeneration and total site targeting. For distillation columns targeting, we can use for batch process targeting and optimization we can use, and we can use for low temperature processes. So, when we talk about energy integration this five topics come to our mind then it can also be used for hydrogen management in refineries. Basically, if you see the PI applications, we go for heat integration and mass integration and the hydrogen management in refineries falls under mass integration.

So, if you see the mass integration also, here we can go for water and waste water management and recovery of valuable materials. We can go then for pollution prevention, we can use basically it is a mass integration and a energy integration process, we can go for carbon constrained energy sector planning. We can go for water and waste water management, we can go for recovery of valuable materials and we can go for emission targeting in this method or in this application area. Then we can go for debottlenecking of critical areas in process industries using pinch technology. We can even use it for financial management, we can use it for supply chain management and we can use for co-production systems. So, we see here that the pinch technology or the process integration as got a broad area of application.

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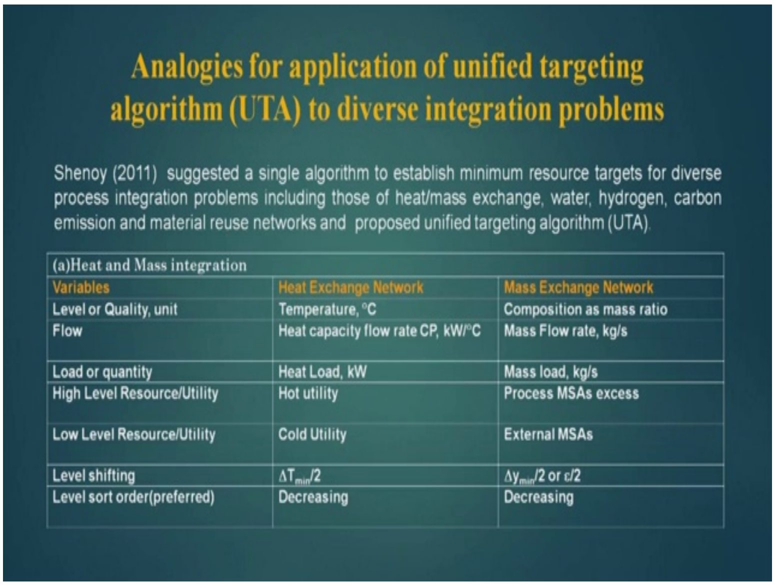

Now to show you that how this is becomes so, broad the application has becomes. So, broad let see the analogies for application of unified targeting algorithm UTA to diverse integration problems. Shenoy in 2011 suggested a single algorithm to establish minimum resource targets for diverse process integration problems including those of heat and mass exchange, water, hydrogen, carbon emission, material reuse networks and proposed unified targeting algorithm UTA.

Now if you see this only we see a part of it that is heat and mass integration. So, the variables for heat exchange network the level or quality is temperature that is the driving forces temperature for mass exchange network the driving forces composition or mass ratio. If I say the flow of quantity for heat exchange network; it is heat capacity flow rate and for mass exchange network, it is mass flow rate k g per second load or quantity. If you see it is heat load for heat exchange network and for mass exchange network this is mass flow rate high level.

Resource or utilities here for heat exchange network hot utility that is steam hot water or Dothan and in the mass exchange network this is process MSA and for low level resources in utilities the cold utilities used for heat exchanger network and for mass exchanger network this is external MSA level of shifting which is used for heat exchanger network is delta T minimum by two and there in the mass exchange network. we use the delta Y minimum by 2 or epsilon by two a level sort orders when we are sorting the temperature levels or the concentration levels that is from in the decreasing order , also mass exchange network it is decreasing order. So, shenoy has given a unified algorithm for the utilization of PI in different areas.

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Now let us come to the pinch technology which is air technology which is being used for process integration. So, it is a methodology for minimizing energy consumption of processes by computing thermodynamically feasible energy targets or minimum energy consumption and achieving by them optimizing heat recovery systems, energy supply methods and process operating conditions. It is also known as process integration, heat integration energy integration or pinch technology.

Aspen Tech’s Nick Hallale, has reported that the pinch analysis for energy has an enormous amount of application with thousands of projects having been carried out all over the world. Companies, such as Shell, Exxon, BP- Amoco, etcetera. Mitsubishi have reported fuel savings of up to twenty five percent and similar emission reduction worth millions of dollar per year, so its shows the effectiveness of the pinch analysis and how this analysis is saving the energy and reducing pollution in worldwide.

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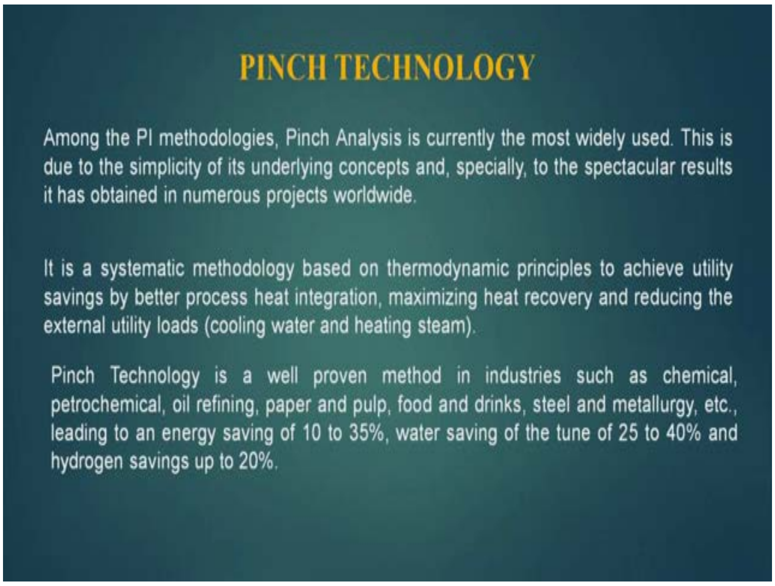

Among PI methodologies pinch analysis is currently the most widely used because it provides a lot of insight to you when designing; this is due to the simplicity of its underlying concepts and especially to the spectacular results it has obtained in numerous projects worldwide. It is a systematic methodology based on thermodynamic principles to achieve utility savings by better process heat integration; maximizing heat recovery and reducing the external utility loads that is cooling water or heating stream. Pinch technology is well proven method in industries such as chemical, petrochemical, oil refining, paper and pulp, food and drinks, steel and metallurgy, etcetera. Leading to an energy saving of 10 to 35 percent, water saving of the tune of 25 to 40 percent and hydrogen saving up to 20 percent.

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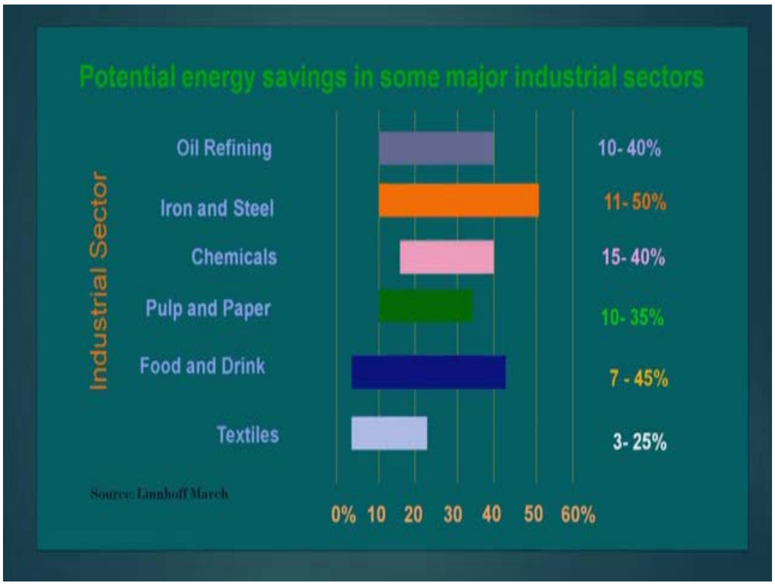

Now, here we see some graphical represents of the saving which it can do. Here, we see the oil refining sectors the saving is from 10 to 40 percent and here we are talking about potential energy saving due to heat integration and in the iron and steel industries. It is 11 to 50 percent for chemical industries about 15 to 40 percent saving can be achieved. paper and pulp 10 to 35 percent of energy saving can be achieved. Food and drinks industries 7to 45 percent and textile about 3 to 25 percent energy savings can be done using the pinch technology.

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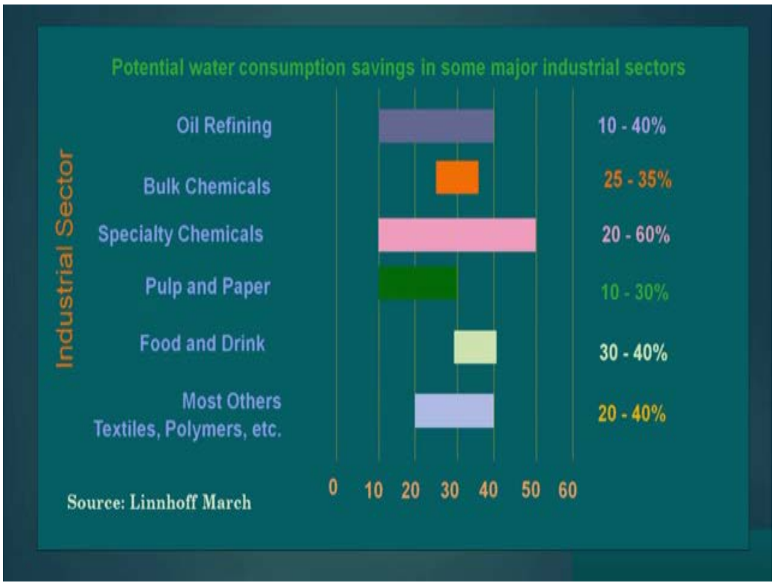

Now, if you go for the water savings then the same technology what is called water pinch. If applied on the industries or refinery it can save 10 to 40 percent of the water, for bulk chemicals 25 to 35 percent, for specialty chemicals 20 to 60 percent water saving pulp and paper 10 to 30 percent water saving food and drinks 30 to 40 percent water saving and most other like textile polymer etcetera 20 to 40 percent water saving, so this is the huge amount of saving which can be done using process integration and when applied to our industry.

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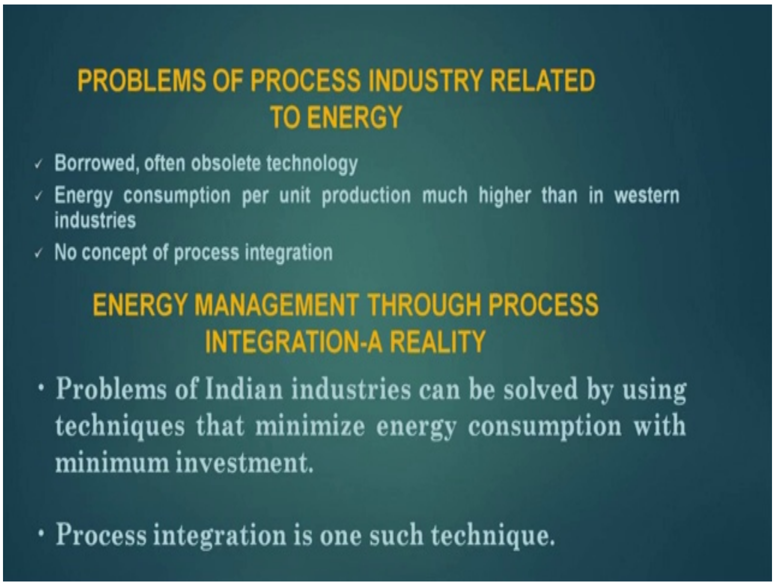

Now the problems of process industry related to energy is that most of the industries in the third word are the technologies borrowed, often obsolete technology, energy consumption per unit production much higher than in western industries no concept of process integration. So, the energy management through process integration has become a reality, the problems of Indian industry can be solved by using techniques that minimize energy consumption with minimum investment using this process integration technique. So, process integration is one such techniques or such one tool which can do a lot of good to our industry.

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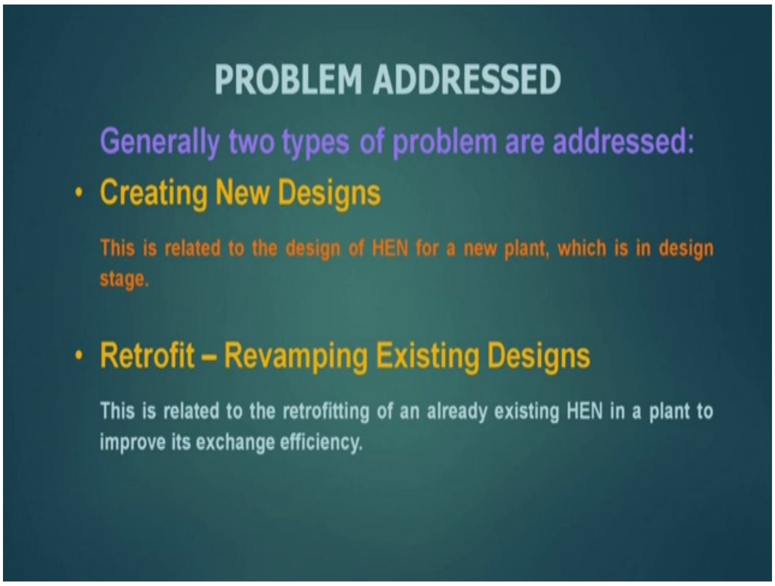

Now generally problems which are addressed are of two types one is called creating new designs and this is related to the design of HEN of a new plant, which is in design stage. and the other is called retrofit or revamping of existing designs even, if you have a existing design we can still apply the process integration or pinch technology to cause saving. This is related to the retrofitting of an already existing HEN heat exchanger network in a plant to improve its exchange efficiency.

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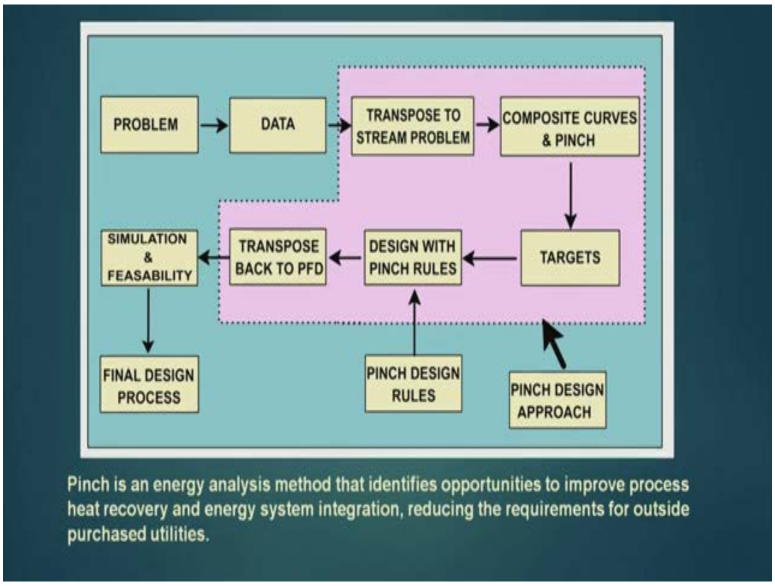

Now, how its work. So, we first take the problem where we want to apply pinch technology or the processes integration. Then we collect the data then we transpose to stream problems and then we draw composite curves then we define our targets which can be energy targets, area targets it can be number of units target number of sales target it can be cost target etcetera then we design to meet those targets. So, design with pinch rules and then we transpose back to a new PFD. So, we start with the PFD of the existence plant and then we give a new pfd based on process integration. And if this new PFD is implemented then a lot of saving can be done. So, once the PFD is with us then we go for simulation and feasibility checks and once we are satisfied with the simulation feasibilities check, then this final design is accepted and implemented in the industry.

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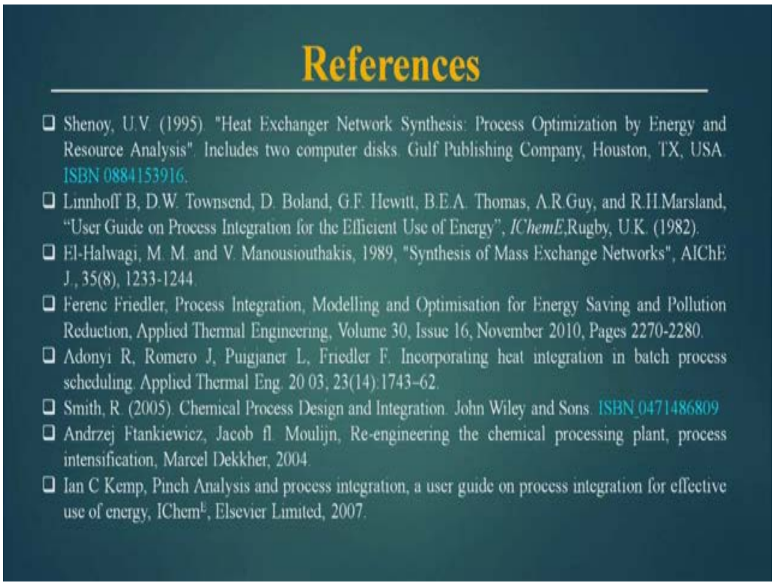

And these are the references.

Thank you.