The Fourth Wave in Chemical Industry:
Thrust on sustainability and energy efficiency as key to the growth in chemical industry

Dr R R Sonde

Paradigm changing technologies have led to huge jumps or shifts in manufacturing, which could be termed as waves. While the first wave for the chemical industry was characterized by the development in unit operations, subsequent waves were propelled by outstanding process chemistries (the second wave) and process intensification (the third wave). Now the fourth wave as an extension of process intensification has led to Pinch Analysis and Resource Optimisation. Now pressures of sustainability and climate change are driving forces for advancing energy and resource efficiency.

This article traces the evolution of various such waves and elaborates on the different energy sources, mainly the emerging ones and its integration into chemical manufacturing.

The spectacular growth of chemical industry constituting such diverse spectrum of molecules & compounds from oil, gas, refineries all the way to agro-chemicals and downstream fine chemicals like drugs & pharma, colorants is owing to decades of path breaking research & development with disruptive discoveries in processes & catalysts on one hand and design of new types of process equipment on the other.

If the first wave in Chemical Industry (CI) is essentially credited to the development of unit operations in minerals & bulk compounds - when you look-back, they appear as inefficient & primitive processes, but let's admit they were pathbreaking at that time -while the second wave belonged to the discovery of outstanding process chemistries. It will be difficult to name only few and leave the rest behind since each of these discoveries led to outstanding new industries. The Haber's ammonia synthesis revolutionized the fertilizer industry, polymerization chemistries and discovery of Zeigler Natta catalysts laid foundation to plastics & polymers. The Second World War as in other sectors, catalyzed host of new processes. Sasol process for conversion of coal to liquid fuels (CTF) became a benchmark for ingenuity of the chemical engineering while the cryogenic processes did not lag in their innovations for making industrial gases. The development index (DI) of any nation got measured in terms of the diversity of chemical molecules discovered / synthesized for enhancing human comfort and experience of life. The second wave thus put a final seal to the primacy of chemical industry in the growth of any nation and thus the giants like BASF / Bayer/ DU Pont/ Dow just to name few became the torch bearer of the CI.

Then came the third wave, and this belonged to "process intensification". The invention of new processes and tools to optimize the performance of the process plant designs enabled to intensify the process plant performance parameters like yield, purity, energy consumption or reduction in waste generation. This is like driving the plant to its thermodynamic limits.

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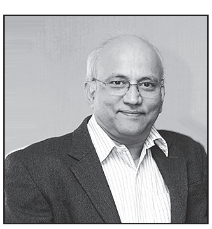
Dr R R Sonde is the Executive Vice President (Research, Technology & Innovation Centre) & Member on Board of Executive Council, Thermax Ltd. Prior to Thermax Ltd, Dr Sonde had 23 years of working experience in Atomic Energy. He is currently the Chairman of the Task Force constituted by Niti Aayog on production of methanol using high ash coal.



The simple mantra in this third wave is the philosophy of "More from Less". It was kind of applying second law of thermodynamics in the chemical industry at an integrated level. De-bottlenecking of many CI processes resulting in enhanced yield & quality of the final products. The example which immediately draws attention is the mass transfer contact equipment. From a discrete contact types of mass transfer devices like trays (bubble cap/ sieve) gave way to structured packingsrevolutionized the transport processes in chemical industry. This led to enhancement factors which impacted not incremental but easily two orders of magnitude (NTU-HTU) leading to making difficult separation process feasible economically. Typically as bench mark design for separation of deuterium from hydrogen (Heavy Water production for production of industrial scale heavy water- this process is often quoted as a gold standard in any separation science process) with a separation factor (β= 1.0014), the design of column needed 7000 contacting stages using a conventional bubble cap kind of trays (with say 485 mm as tray spacings) requiring 3500 m of column height (looks ridiculous today!) and this could be brought down to less than 75 m of column using structured packings. Besides resorting to a reactive distillation process the separation factor was boosted from 1.0014 to 2.3 which mean that (1- β) factor increased 214 times.

There are number of examples on process intensification strategies. New types of stirrer design for the reactors, spinning band distillation columns, centrifugal mixer & settlers, plate heat transfer equipment, fluid bed reactor systems so on and so forth. Chemical industry gained tremendously from such efforts and kept them going in the face of stiff global competition. It was not merely the size of the process plants but use of innovative

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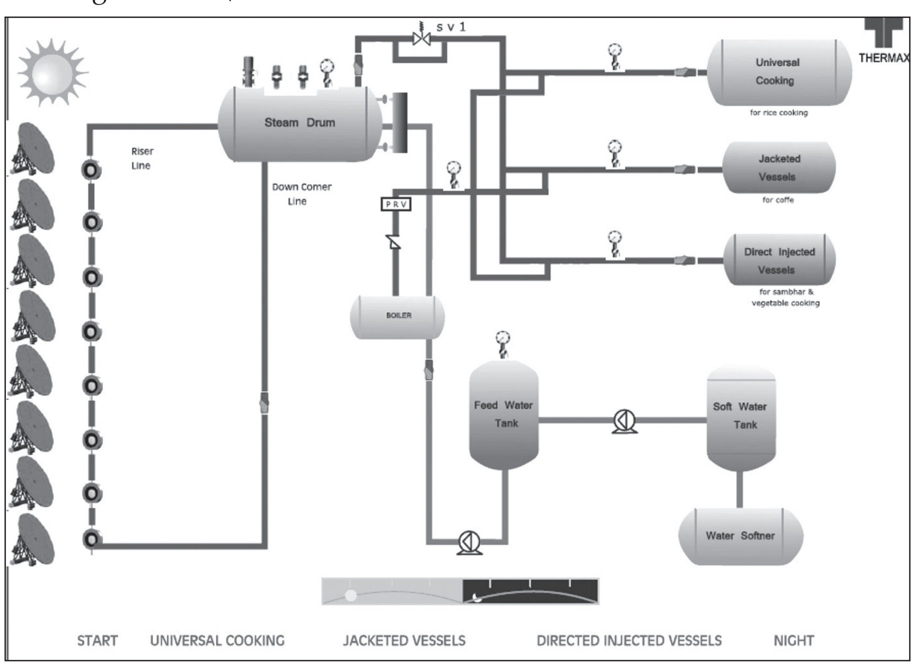

Fig 1a: Integration of concentrated solar thermal into an existing steam boiler. A concentrating solar dish is integrated with conventional steam boiler to reduce the carbon foot print due to heating needs of the process.

designs which mattered the profitability and opened new vistas in design & engineering of the process systems.

Now the fourth wave. The fourth wave which in fact began as an extension to process intensification with "Pinch Analysis & Resource Optimization" as new optimization tool. This paper will not dwell in detail on this process but suffice to say that today Pinch analysis is accepted as the best measure to understand the energy extraction potential of any complex process. This tool is very handy to the system integrators where the entire process complex was analyzed from the resource optimization point of view. Instead of a local optimum, efforts moved towards looking for the global optimum and hence the "pinch" of the process plant complex became a very convenient mechanism to measure the energy intensity of the process.With novel heat exchanger designs using multi-channel designs / nano particle enhanced heat transfer coefficients / plate heat exchanger for even high-pressure systems have enabled using much lower temperature approach leading to higher energy recovery. The direction of research in this wave is to move rapidly on one hand to integrated energy management principle and on the other design of smaller & discretized scale of chemical process plants. Chemical plant in a suitcase if one would like to call it! The main motivation for this fourth wave is the sustainability concept in this resource challenged world today. The three pillars to this sustainability are safety of the complex systems, climate change challenge and zero emission design. Integration of the chemical complex with RE (Renewable energy) is the answer to this sustainability. The main features of this are discussed in the following paras.

A. Integration of renewable energy systems in the chemical process industry: Energy in the form of heat (& cool)

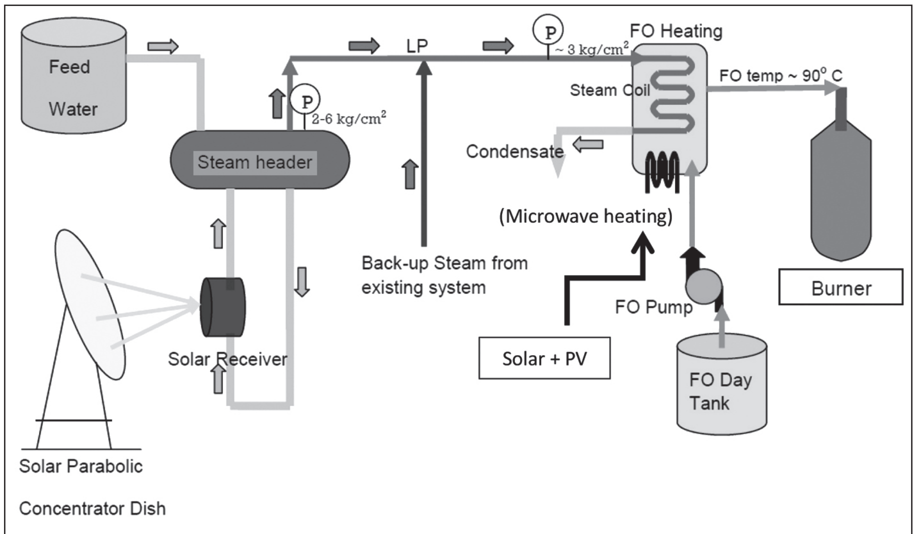

Fig 1b: Solar thermal and solar PV integration where the electric heater (or any microwave heating system) use solar PV power.

Heat loss due to steam pipe system can be avoided if process heating application can be met using PV power and electromagnetic heating process. The crash in Solar PV costs has made this option feasible.

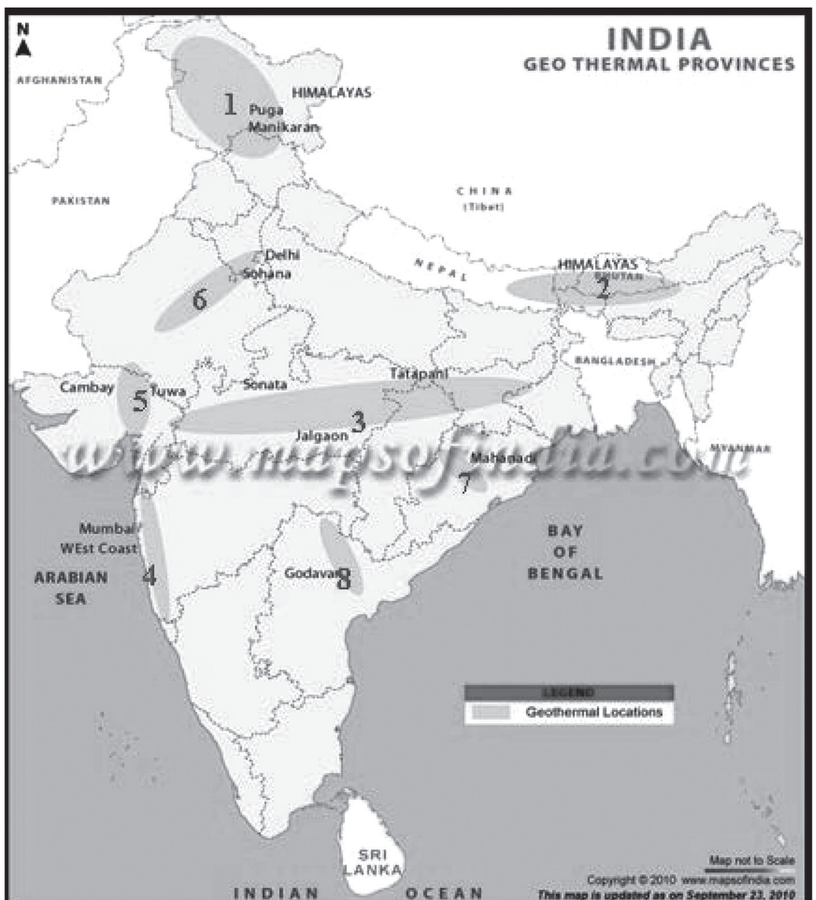

Fig 2: Geothermal energy resource in India

Geothermal energy can be tapped from geothermal sources to provide process heat on a 24/7 basis. Shallow geothermal energy is also possible to be used for process cooling avoiding the open cooling tower systems.

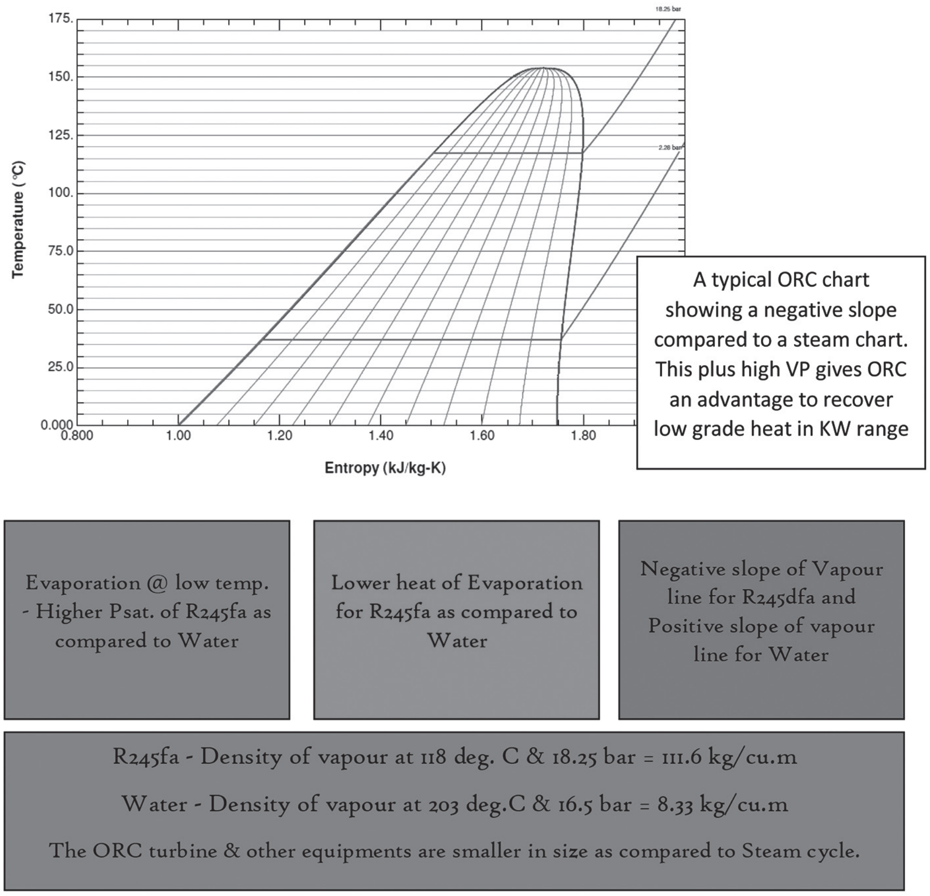

Fig 3: A typical ORC thermodynamic chart

ORC from 30 - 300 kW using a twin screw design can be integrated at manyplacesin process plant. The "Pinch" technology for heat integration can use ORC as the ultimate heat regulator in any process plant.

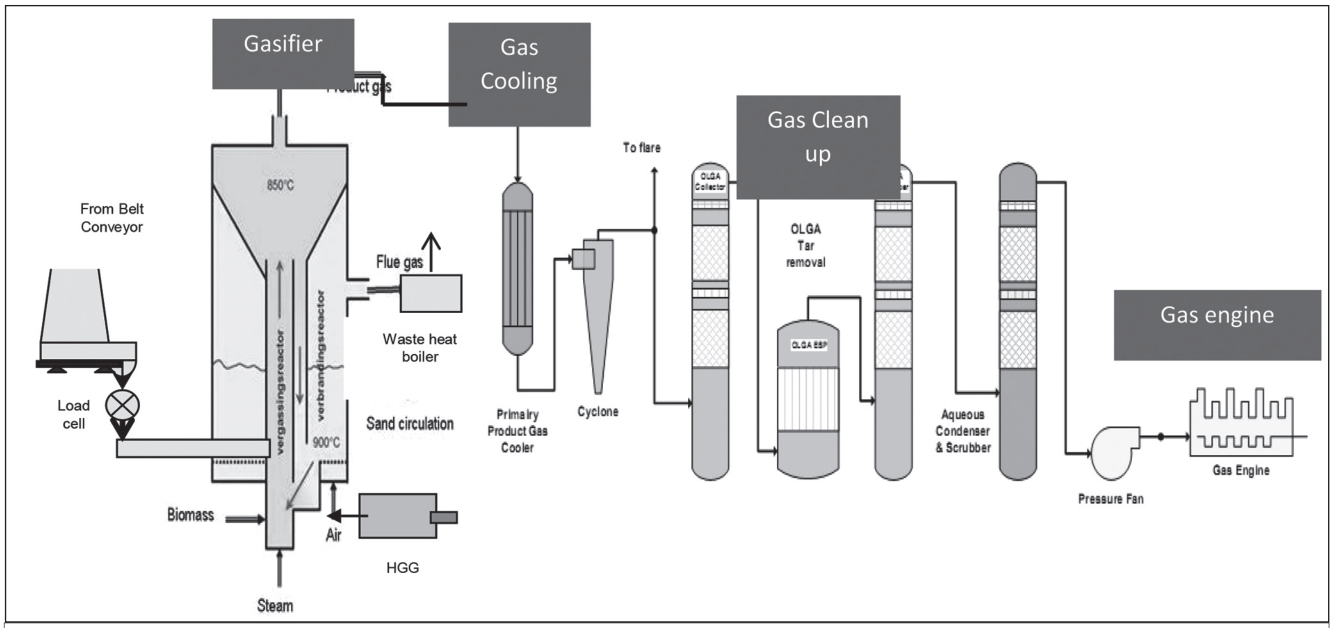

Fig 4: A twin bed fluidization for industrial / agro waste conversion to power / synthetic natural gas.

A novel technology to generate clean bio fuels and power using a twin bed design to take care of agro residues, industrial waste or MSW. This plant can handle 10-100 TPD waste andgenerate SNG or S-methanol.

and electricity is used in all the process industries. Renewable energy will have to now take a major share of this energy. And in that solar-wind-geothermal-biomass are the sources to be used in the process industries. Process heating requirements can be fully met by using concentrated solar systems. From hot water at 80ºC to high temperature systems needed in mineral processing plants at 400ºC can be provided by different types of concentrators. Currently the designs will be in hybrid concept where the existing steam generation will be hybridized with solar. This integration can happen at different levels. From feed water heating to main steam supply level. Fig 1 (a & b) shows one way that a solar thermal can be integrated in any process industry and use concept of solar boiler in place of conventional fossil fired boilers. The next challenge is to design a low-cost thermal storage system so that solar heat can be made available on a continuous basis. There are lots of research taking place in finding a cheap and safe way solar thermal energy can be stored. Moving away from a conventional phase change material (PCM) or salts, use of low cost ceramics / concrete / scrap materials are becoming a source of low cost thermal energy.

B. Wherever geothermal energy is available- and there are few places in India where good quality geothermal energy exists in India, see Fig 2- heat from the geothermal can also be used in the process. The main advantage is that geothermal energy is more firm and can be tapped on 24/7 basis. Geothermal source can also be used to generate sub ambient cooling/ chilling needs of the process plant using vapor absorption cooling technologies.

C. Solar PV has now become ubiquitous renewable electricity and roof-top systems are now a given thing. The way the costs of solar PV power is falling, it may not be too distant future to assume solar PV power is free and in that case use of electricity for thermal energy needs will become a serious option to be examined. That is when the micro-wave or electro-magnetic based heating systems will become the best way to provide direct heat to the reactor systems. This will eliminate the complex & leaking steam & condensate systems causing heat losses. An electrical wired power and an EM source close to demand point will be most elegant way to provide the thermal energy needs of the processes.

D. The un-utilized heat from the process industry is another Goliath which has been never addressed in any comprehensive way. The new concepts of using Organic cycles or Super critical CO_2 cycles will now make conversion of waste heat to useful power a possibility. The nature of these new systems (new organic molecules in ORC) makes this eminently possible. Fig 3 gives shows a typical advantage of use of ORC to generate incidental power wherever such heat exists without the need for collecting the heat and then setting up of poorly efficient steam cycle.

E. Biomass or agro-residue or waste mass from the process industry today is today a source of rich hydrocarbons. The new processes available today to convert this into hydrogen or hydrogen carrying fuels (like methanol / ammonia / LOHC-Liquid Organic Hydrogen Carriers) can make the process industries rich in generating green fuels using its own internal waste or the bio residue cultivated as energy crops in its neighborhood. There are both bio-chemical/enzymatic/ catalytic/ thermo-chemical processes available for such conversions. Indeed, this can make the process industry not simple the consumer of energy but prosumers (producer-consumer) of energy. Fig 4 shows one such way of conversion of lowest from of waste to rich quality synthesis gas.

The above examples are but few in the array of new systems available in the kitty of engineers & scientists to make the fourth wave of chemical industry a self-sustaining entity. The fugitive emission control technologies integrated with energy efficiency technologies makes the new generation chemical industries smart, efficient and zero emission systems.

Process optimization and control is an all-time favorite subject to a process engineer. Today undoubtedly the use of AI tools and the IOT platform provides an immense opportunity for him to raise the level of optimization techniques. Use of new algorithms is going to revolutionize the chemical industry. And when we use many of the above concepts of integrating the processes with new energy systems some of which are not "firm" in terms of their availability but the plant needs the energy (inputs) in an uninterrupted manner, the advanced neural network based tools will enable such integration with least interference to the process but at the same time making the process highly sustainable. That is the way forward to the new generation emerging chemical industry landscape. And to conclude some of these concepts can well be retrofitted in the existing process plants including the smart control systems using new wave sensors.