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Data Analytics in Chemical Engineering and Process Industry

Tushar Goel
Artie McFerrin Department of Chemical Engineering, Texas A&M University

Insights from advanced data analytics are helping engineers make better business and operational decisions to increase productivity, efficiency, reliability, safety and hence profitability. Many energy firms now recognize data as a natural resource [1,2]. Today, if one carefully venture through the profiles of the Big Oil companies and leading technology providers, it is not hard to observe that most of them have invested in the field of Big Data Analytics (BDA) in anticipation of harnessing the benefits of cheap computational power and large quantity of available data. BP has been using analytics to dampen the effects of market price fluctuation on their trading business. Dow Chemical Company has been researching in this field for over a decade now and they have successfully deployed various applications (e.g. inferential sensors) in their processes [4]. KBR has developed a strategic partnership with IBM to setup a new division called Cognitive and Big Data Analytics to provide Predictive Analytics and Machine Learning (PAML) and Cognitive Computing services. So why is this trend so important? Why shift away from fundamental thermodynamics based analysis to a pure data driven analysis?

Oil, gas & energy and Chemical Process industry has been collecting a huge amount of data from the operation of facilities as well as during project and revamp phases. At manufacturing facilities, process parameters like temperature, pressure, flows, vibration, current etc. are the bare minimum requirements to monitor and control a process. Hundreds of such parameters are recorded on per second basis but mostly monitored in a univariate manner, often plotted as charts and graphs. It is a challenging task to simultaneously monitor multiple variables or identify the deviations fast enough to prevent the upset in process. For improved performance we need to move from reactive to predictive approach which requires multivariate monitoring. One example is Enterprise Manufacturing Intelligence (EMI) platforms that are used to show Key Process Indicators (KPIs) and alert the operator on deviation that have already occurred or are expected to occur in short term based on various symptoms. Recently, Honeywell has come up with Intuition Executive (IX) platform that uses Cause and Effect relations to systematically arrange process variables, parameters and KPIs in multiple layers. The user start with top layer of information which gives a condensed overview of overall production performance. If there’s a deviation then the second layer will provide the states of potential causative factors which are again dependent on the third layer parameters and so on, till this drilling down reaches to the ultimate measured process variables, which are all in the last layer. One of the limitations of this approach, in my opinion, is that the monitoring scheme is only as good as the underlying cause effect relations. Hence, analyzing data on a standalone basis can augment the understanding of root causes of faults. Latent variable and Artificial Neural Network are some of the techniques which can come handy in these applications. (CLIP technology in action [3]).

With the Industrial Internet of Things (IIoT) increasingly gaining momentum and sensors becoming more affordable, it is estimated that the data generated will be in the order of Exabyte (1019). Today, transmitter are faster, cheaper and more accurate than before, hence data measurement and collection is not a limitation anymore. Developing the ability to make sense out of it fast enough is the true challenge. The vision is to use as much data as practically available including ambient conditions data, supply chain schedule, market fluctuations and of course process data to better plan & predict the path of process and control it optimally, preferably in fully automated manner. Model predictive control techniques have been used for quite a while now to optimize the process control but their underlying model reduction and simplifications have restricted their use as a fully reliable independent controllers.

It is not far when the industry will be realizing major improvements in operation management, troubleshooting and optimization by using BDA. Using proper tools we can harness the potential of raw data to mitigate risk at project stage by gaining insights from advanced & realistic prediction of project progress, planning and variability rather than personal estimates and unrealistic targets. We can design improved processing technology packages and control systems to achieve higher nameplate capacities, yields and efficiencies by utilizing the synergy between first principle modelling and data driven models. The concept of digital twin is often referred in these discussions. Traditionally, process engineers have been using commercial simulation software packages from Aspen, Honeywell, KBC, Schneider etc. to model and simulate the process plant. A few issues with this approach are intensive modelling efforts required, model accuracy is as good as the designers' knowledge, and deviation of actual performance from the idealistic model. Often, the models are calibrated using plant data but the choice of parameters is still subjective. Data analytics provides tool and intelligence to better replicate the actual performance, to analyse process data in real time even though the parameters do not vary in sync due to different residence times in process. This will facilitates predictive monitoring of upsets to make better judgement as well as informed control decisions. This lays the path to advanced versions of EMI platforms that are capable to display the future conditions of the plant in front of operator in real time and show effects of external control actions with acceptable accuracy. A detailed review of current state of Big Data Analytics (BDA) based applications and techniques is present in [3] where Leo Chiang et al. have mentioned applications specific to industries and production scales.

United States has set up multiple institution under their Manufacturing USA network. Clean Energy Smart Manufacturing Innovation Institute (CESMII) is one such initiative. The focus of this Institute is to research and develop technologies and solutions that can capture, share, and process in real-time the increasing amounts of information available at manufacturing facilities. CESMII's Southern Regional Centre is hosted at Texas A&M University. The project undertaken by this regional centre in collaboration with other universities and industry members is aimed to develop Smart Manufacturing (SM) Platform-ready tools that harness the power of advanced optimization techniques, data analytics, hi-fidelity modelling and commercial software applications. The synergistic use of these solutions in cyber-physical environment is indeed a realization of the 4th Industry revolution and a proof of concept of various academic developments.

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Mixed Thiol Monolayers on Gold Nanoparticles: Preparation, Structure and Properties

Debdip Bhandary
Research Scientist, HPC & Computer Centre, Indian Institute of Technology Kanpur

Gold nanoparticles and colloidal particles have found its applications extensive as a part of medicines since ages. Gold nanoparticles (AuNPs) properties can be fine-tuned by grafting ligands onto them such that the physicochemical properties of their surfaces are controlled by the structure and chemistry of the anchored ligands. The properties of the coated AuNPs can be controlled by changing the arrangement of the molecules in a mixed-thiol coating, such as random, stripe/patchy and Janus. Moreover, the Janus particles (JP) have an asymmetry in a structure that can impart diverse functionalities leading to immense importance in various applications, ranging from targeted delivery to interfacial phenomena, including catalysis, electronics, and optics.

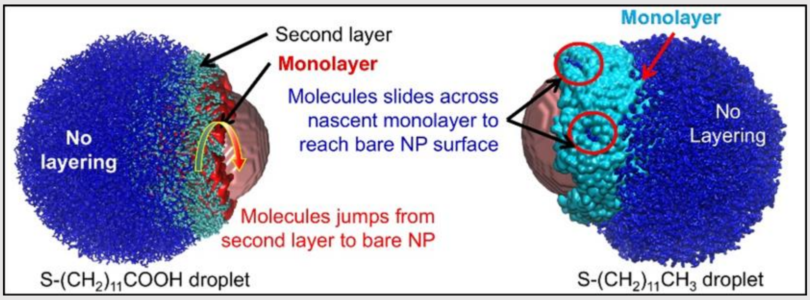

Figure 1**:** Different propagation mechanism from a droplet of thiols with different functional groups (left). Hydrated mixed-thiol coated nanoparticles at different arrangements – from left to right: random, stripe and Janus respectively (right). Color: red and white sphere for water and blue, green surface for CH_3 and COOH groups respectively (right).

The preparation of the thiol-coated AuNPs is a time-consuming one. Using molecular simulations, we predicted the possibility of formation of such coating by controlling merely the droplets of thiols and its chemical nature, and it can be utilised in the microfluidic synthesis. The growth mechanism of monolayer from the droplets of thiols with different chain-lengths (C_5 and C_{11}) and terminal groups (CH_3 and CO_2H) was investigated. A two-step mechanism, obeys first order Langmuir isotherm, initiated by binding of the droplet to the nanoparticle surface with a time constant of the order of one nanosecond, and followed by diffusion driven-growth with a more significant time constant (~100 ns), captured the growth dynamics. Due to strong hydrogen bonding between the carboxyl group and higher cohesive interaction between longer thiols slow down the dynamics. However, the kinetics of n-alkyl thiols coating on the nanoparticles is found to be independent of the droplet size, but carboxyl-terminated thiols spread more with increasing droplet size.

Furthermore, different time constants for different chains and functional groups yield a phase-separated coating when two droplets of alkyl-thiols with different terminal groups are allowed to form monolayers on the nanoparticle. The Janus balance (β), the ratio of surface area covered by alkyl thiols to that of the NPs, for a different combination of alkyl-thiols as well as of nanoparticle sizes, varies in the range 0.42-0.71. Implementation of this methodology in microfluidics would undoubtedly reduce the procurement time.

These SAMs serve as a linker between the NP and its surroundings, providing essential properties, such stability and solubility. The behaviour of this kind of NP assemblies' depends on the structural arrangements that are governed by the bending of the molecules and interaction between tail groups. A different arrangement of the molecules, such as random, patchy/stripe and Janus, in the coating, leads to change in their structure in mixed SAMs. The tilt angle of the molecules and radius of gyration (R_g) of the whole assembly indicated that the structural morphology of mixed SAMs on AuNPs depends on arrangement, carbon chain length and chemical composition of terminal groups of thiols. Due to the different affinity of the groups towards the water, the hydration of the NPs changes with arrangements, as shown in figure 1(right). This property finally leads to different behaviour toward lipid membranes.

Structural properties of SAMs and surface hydrophilicity are dependent on the arrangement of thiols for mixing of unequal carbon chain lengths. Hydration of SAMs-protected gold NPs does not only depend on the molecular composition of the thiol, but also on the organisation of mixed thiols. Also, the bending of longer thiols when it mixed with shorter thiols depends on the arrangement of thiols as well as the terminal groups' chemistry. This bending has a strong impact on the structural and hydration properties of these NPs. The bending of longer thiols increases with the stripe thickness of mixed SAMs of equal and unequal lengths coated on AuNPs. The structural morphology and hydration of the coated SAMs also depend on the thickness of the stripes. Our results show that the structural and hydration properties of SAMs are affected by the stripe thickness for mixtures of alkyl thiols with unequal chain length but not for equal length. Hence, the stability of the stripe configuration depends on the alkyl's chain length, the length difference between the thiol mixtures, and solvent properties. Therefore, judicious choice of the above parameters would make it possible to obtain stable stripe configuration. A better understanding of the microscopic picture of the stripe configurations arising from various relative length differences of thiol tails on 4.0 nm size AuNPs was projected in this study, which has relevant implications for biological processes. For instance, the findings regarding the hydrogen bonding between water and thiols show the binding nature of the various stripped AuNPs with any other foreign molecules that are used for potential applications.

Acknowledgement:

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Tribo-electrostatic and its application in coal preparation

R. K. Dwari, Scientist
Mineral Processing Department
CSIR-Institute of Minerals and Materials Technology, Bhubaneswar, Odisha, India

Tribo-electrostatic charging has several engineering applications such as electrophotography, electrostatic powder coating, drugs delivery, fire hazard and safety, and particulate separation [1]. Tribo-electrostatic separation, a dry method has gained considerable attention in recent years in the field of mineral processing, coal preparation and recycling industries.

Indian coals are inferior in quality with high ash content and near gravity material. The coal washing has become difficult due to poor liberation. The condition is further deteriorated as good grade coals are being depleted. The existing coal resources require fine comminution to liberate the particulates for efficient physical separation. With increasing water scarcity, tribo-electrostatic separation becomes an attractive and alternative method.

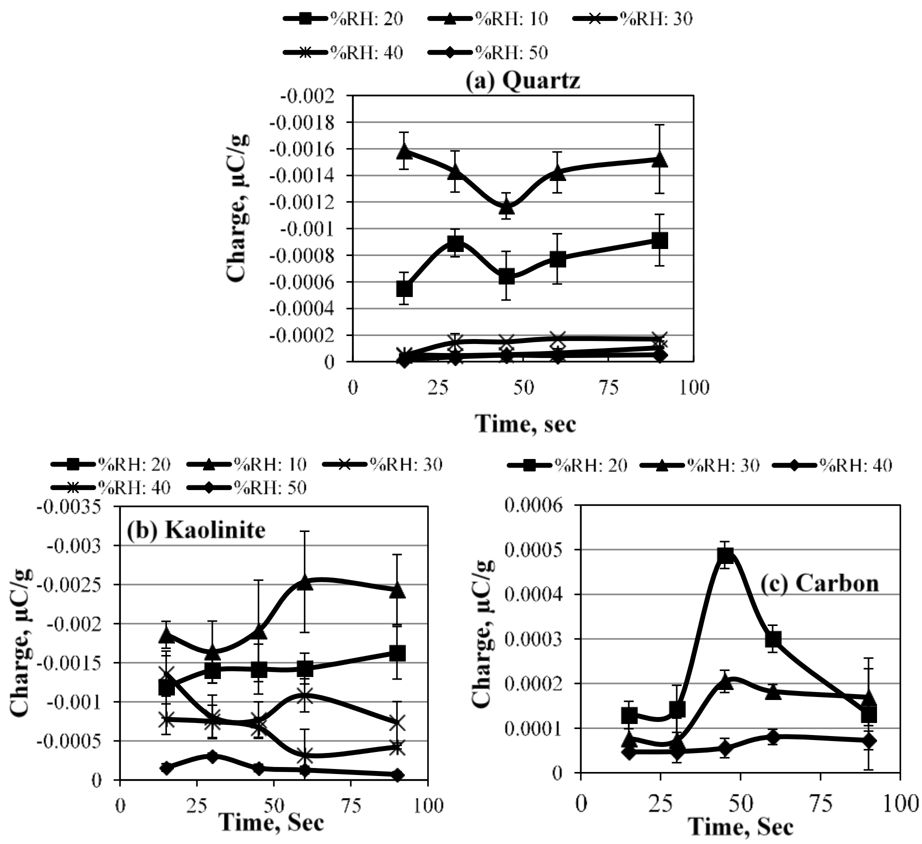

Figure. 1. Effect of humidity and tribo-charging time on the charge acquisition of the (a) quartz, (b) kaolinite (c) carbon particles with copper tribo-charging medium [5].

The process mainly consists of two steps: particulate tribo-charging and separation of charged particle in an electric field. During contact electrification, particles get charged on contact with another particle or with the surface of other material. The polarity and magnitude of charge acquired by the particle are based on their work function difference. We have established in our studies [2-4] that the carbon charge positively while mineral such as kaolinite, illite, and quartz charge negatively on contact with copper tribo-charging medium. The humidity has an effect on the tribo-charging of the carbon and minerals (Fig. 1) [5]. The factors that affect the efficiency of tribo-electrostatic separator are classified into

into three types: (1) particulate physical properties such as shape, size, density, surface state and purity, (2) relative humidity (RH) of the environment (3) charging medium material; operating variables of tribo-charger and free fall separator. Different types of tribo-chargers such as vibratory feeder, cyclone, fluidized bed, and pneumatically conveying through pipe were developed to generate high differential charge between the target and reject particulates during contact electrification for their efficient separation in an electric field [1-3, 6].

The controlling variable in a free fall separator is the electric field strength between the plates that determine the particle trajectory. There are different particle trajectories for the same mass with the different magnitude of charge and the different mass with the same magnitude of charge. If the particle trajectory is parabolic it may hit the plate and bounce back to the bins beneath the different plates resulting in improper separation. In most of the free fall separators, the plate arrangements are either parallel or inclined at a particular angle. Therefore, for an efficient tribo-electric separation, it is necessary to have optimized plate angle for efficient separation. Dwari et al., 2015 [1] formulated a mathematical model based on the design and operating parameters of the experimental set up to simulate the particle trajectories. The particle trajectories were simulated using measured physical and electrical properties of mineral and carbon particles at experimental design and operating conditions (Fig. 2). The simulation and experimental results were in good agreement. The optimum separation was achieved at a plate inclination of 5º. It was possible to reduce the ash content by 10% at 61% yield (Fig. 3 (a). The preheating of particle is required prior to tribo-charging and the effects of temperature on the coal separation is shown in Fig. 3 (b).

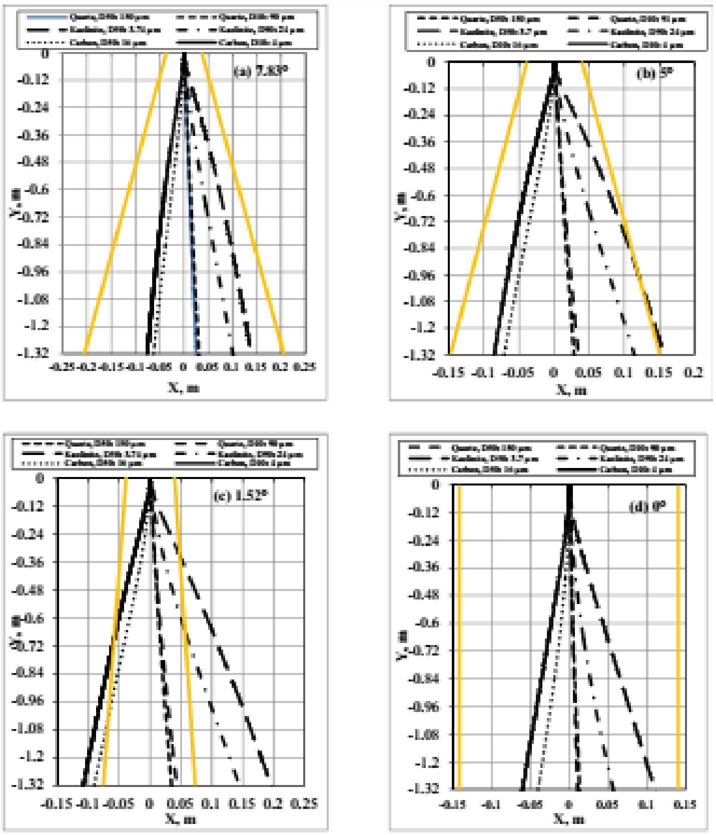

Figure. 2. Simulation of particle trajectories at different angles of plate inclination (a) 7.83°, (b) 5°, (c) 1.52° and (d) 0°

The polarity and magnitude of charge acquired by the particle are based on their work function difference. Hence, the work function is the driving force for the acquisition of differential charge between the particles. The transfer of electron occurs between them until the Fermi levels equalize [7,8]. It is well documented that electron donation and acceptance are the inherent properties of the particles based on their work function. During frictional charging, the surface properties of materials control the electron transfer [7]. Two of the key factors that determine the trajectory of a particle in an electric field are its magnitude and charge polarity. The particle with higher charge magnitude travels a longer distance in an electric field [1]. Therefore, it has a better possibility of separation. It is reasonable to believe that the charge magnitude may increase by widening the work function difference between two dissimilar materials. We have established in our research work that the surface energy of a particle changes during contact electrification [9].

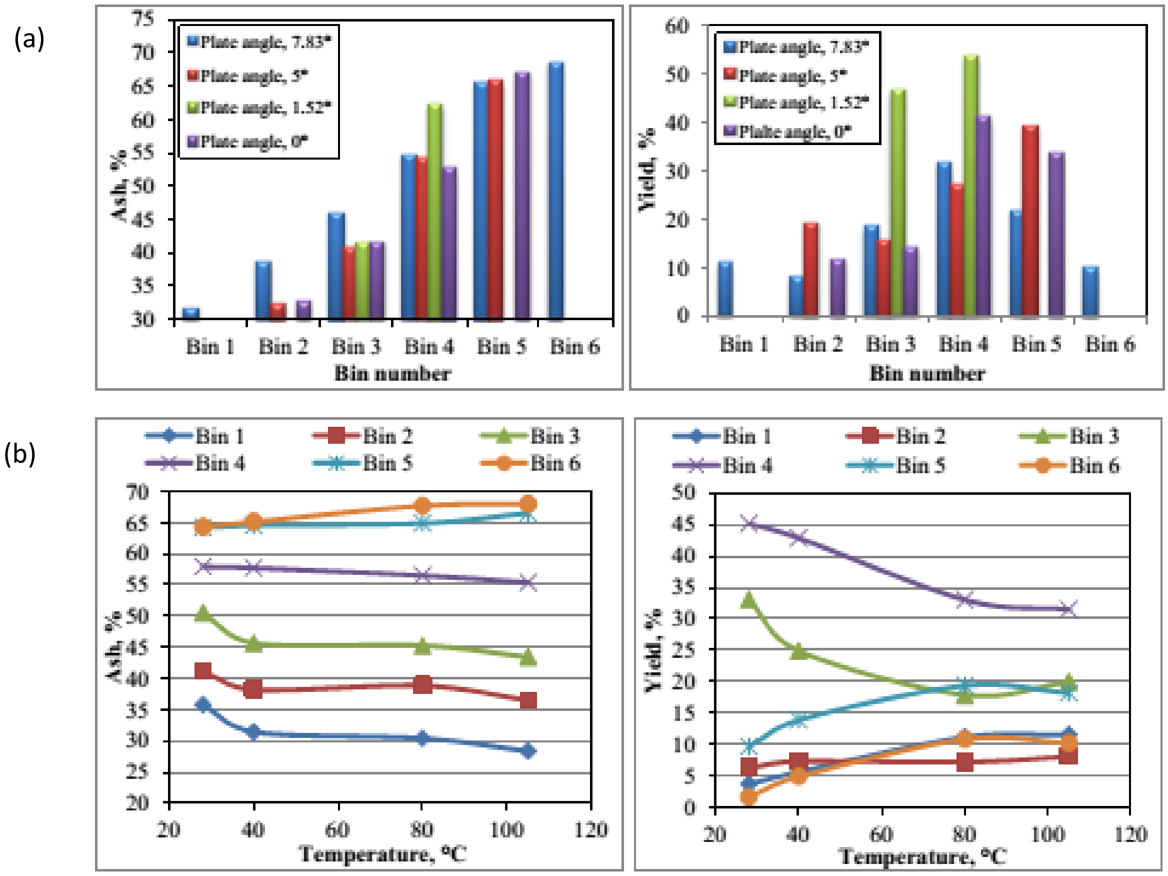

Figure 3: Effect of (a) plate angle (b) temperature on the tribo-electrostatic separation of coal [1].

There exists a correlation between the charge generated by the particles and their surface electronic state, either acceptor (acid) or donor (base). Thereby, a correlation also exists between surface energy and work function [9, 10]. Consequently, an artificial modification of surface energy may also alter the work function. The adsorption of molecules on the organic and inorganic substrate is an attractive approach to control the surface and interface electronic properties [8]. It is a well-established fact that the Fermi level is modified by surface functionalization [8]. Charge transfer to and from the adsorbed species can shift the Fermi level by a significant fraction of an electron volt [11]. Therefore, the donor/acceptor properties of the material can also be altered by surface functionalization. Recently, we have worked out to modify the work function of coal and quartz by chemical treatment. The work is recently published in Powder Technology journal. The change in work function of coal and quartz on treatment with aniline is shown in Fig. 4 [12]. The work has opened a new area of research in mineral processing applications.

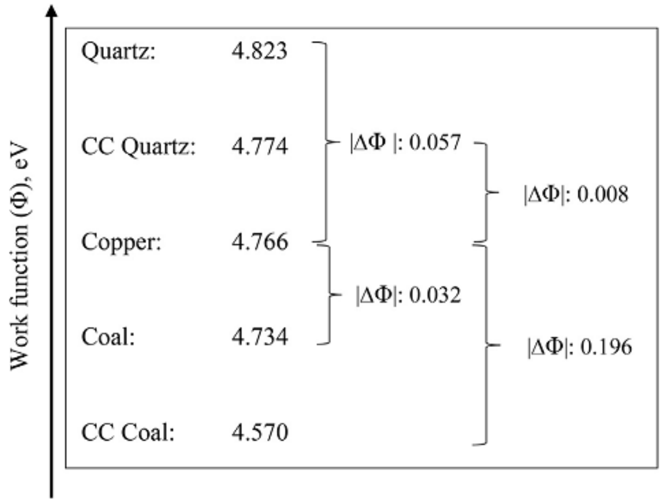

Figure 4: Schematic diagram of change in work function between charging medium and particle before and after chemical condition with aniline [18].

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Breakthrough Technologies in Chemical Engineering

Aditya Suru

Each time humanity has moved a step ahead, chemistry has had a huge role to play in the advancement. In fact, the early stages of humanity have been named after the dominant materials of that era: Stone Age, copper Age, Bronze Age. With time, the complexity of the materials has shot through the roof, with humanity entering the steel age, the age of the polymers. The current age has been deemed as the age of the nanomaterials.

Materials and the articles which man made from them have shielded humanity from the fury of nature. For an example, Haber's process of producing ammonia which led to the mass production of fertilizers upon which half of food production depends [1]. With security from natural calamities, the human population exploded in the last few centuries and a new challenge stood before the engineers: producing materials at a scale to meet the rising demand. This is where chemical engineering comes in. Chemical Engineers solve the problem of production at a very large scale. A chemist finds a formula for a drug and a synthesis process, while a chemical engineer solves the problem of taking the drug to a billion people.

From its humble beginnings as unit operations, chemical engineering has blossomed into a highly multidisciplinary field, concerning itself with the challenges in chemistry, biology and physics and novel production techniques. Through this article I wish to introduce to the reader a few of the inspiring and innovative technologies which come under direct or indirect purview of chemical engineering.

Carbon 3D's CLIP [2], a technology straight out of science-fiction movies is a highly powerful form of 3D printing. Conventional 3D printing is an additive manufacturing process in which a material is deposited in discrete layers to get a 3D object. CLIP makes this process continuous with the help of photopolymerizing a liquid resin into desired 3D object by controlling the projection of light onto the resin. This new approach to 3D printing is about 100 times faster than traditional 3D printing.

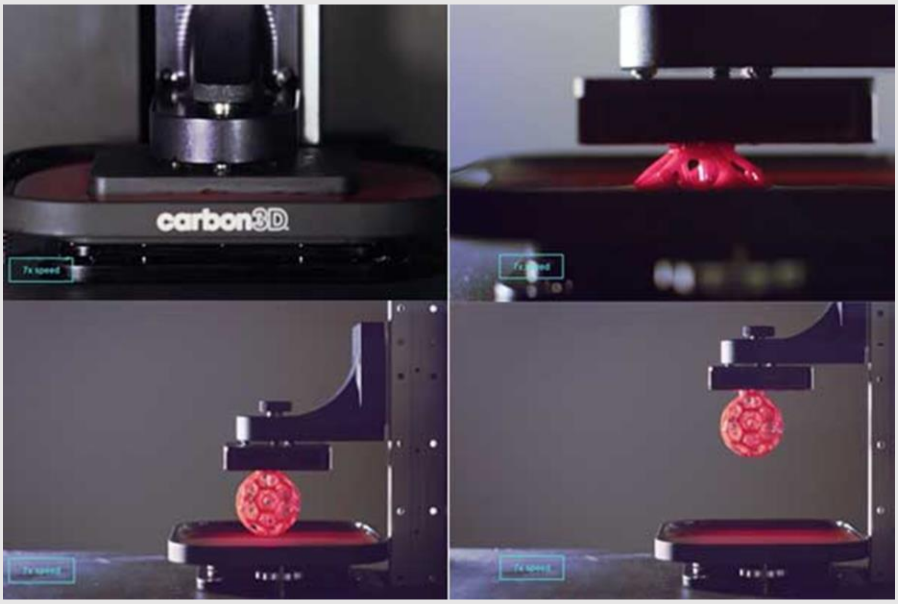

Figure 1: CLIP technology in action [3]

Email: aditya.suru95@gmail.com

Another such breakthrough technology from the same innovator (Dr. Joseph DeSimmone) is Liquidia Technology's PRINT Technology [4]. PRINT is a particle engineering platform which uses particle molding technology to precisely produce drug particles with independent control over size, shape and composition.

Such a paradigm shift is necessary in the production of fine and specialty chemicals, especially in high growth economies such as India, where the fine and specialty chemicals is expected to grow at nearly twice the rate of overall economy. CSIR's INDUS-MAGIC [5] program is aimed to achieve this paradigm shift by developing MAGIC (Modular, Agile, Intensive and continuous) processes. One of the applications is in the pharmaceutical industry, where a majority of operations are either batch or semi batch. MAGIC processes aim to intensify these current production methods into a safer, cleaner and much more efficient processes. Miniaturizing the processes has tremendous advantages, such as better mixing, heat, mass transfer and scalability, over the traditional methods while maintaining the throughput. This is achieved by using micro-reactors, static mixers and micro-heat exchangers. This has tremendous potential to revolutionize the pharmaceutical industry by enabling scalable production of complex chemicals in an intensive telescopic process.

An interesting applications of microfluidics is in the field of particle separation. In 1960s, it was observed by Segre and Silberberg that when a dilute suspension of neutrally buoyant particles flowing in a tube in laminar flow regime, the particles tend to equilibriate at a distance of 0.6R from the tube's centreline. In recent years this phenomenon was leveraged to separate RBCs, tumour cells from blood at high throughput [6]. This passive separation process is in sharp contrast to conventional membrane based systems in regards to power consumption, scalability and maintenance.

MEMS and NEMS (Micro nano electro mechanical systems) has paved way for development of point of care diagnostics. In remote villages where bulky and expensive diagnostic instruments are not available, POC devices have made available hand held diagnostic instruments for applications such as detection of adulterants in milk, detection of blood sugar levels etc.[7].

Although not being exactly related to the core topics of chemical engineering, the inventions of Dr. Manu Prakash of Stanford University need to be mentioned when speaking about POC devices. Dr. Manu Prakash, winner of the "Genius Grant" (Macarthur Fellowship) has made world's cheapest paper based microscope powerful enough to see microorganisms. (Foldscope) [8] and the world's cheapest centrifuge which can achieve speeds upto 125,000 RPM (Paperfuge) [9].

A smart material is a class of materials which can respond to change in environment (stimulus) by change in some properties. For example piezoelectric material which can generate electricity on application of mechanical stresses and vice-versa. Although the applications of smart materials are plenty, BLITAB [10], a start-up which is making an iPad for the blind, is a powerful example of power of smart materials used to bring the gifts of the internet and electronic revolution to all the classes of society.

Polymers are ubiquitous in today's world and mentioning even some of the most useful applications would fill an entire book. But this one example shows how powerful polymers can be. A research group at Caltech, in collaboration with NASA's Jet Propulsion Lab has developed an additive to jet fuel which can reduce the post impact explosions that occur during accidents making fuel much safer [11].

Concepts of chemical engineering have far reaching application in a various fields such as such as protein folding and misfolding. A protein is a macromolecule made up of 20 amino acids, which is a crucial ingredient in various functions in living body. A protein acquires its 3D structure by a process called protein folding. Activity of a protein is highly dependent upon its shape and orientation, hence any disruption in this shape will lead to loss of activity resulting in critical diseases such as alzeimer's. Powerful tools such as Molecular Dynamics Simulations enable scientists to study how various proteins fold and unfold under different environments and how the misfolding can be mitigated [12].

One of the most profitable bonds in nature is the O-H bond of water. Breaking that bond efficiently will be a huge step ahead in the development clean energy and replacing the hydrocarbon. On breaking the O-H bond by electrolytic processes, hydrogen and oxygen gases are generated. The oxidation of this hydrogen can be used to supply energy without any harmful products since the product on oxidation of hydrogen is water. The main challenge is storage of hydrogen and efficient cleavage of the O-H bond. There are several groups at IIT Guwahati who are working on addressing these challenges. One group is developing a Palladium based membrane – reactor to generate hydrogen from alcohols [13], while another is working on developing metal/TiO_2 based optofluidic device aimed at water splitting [14].

Graphene, deemed as a miracle material, has found its application in the hydrogen economy. It was found that reduced graphene oxide when functionalized with Eosin Y, a dye often used for biomedical applications, was able to photocatalytically produce hydrogen gas from water. This has the potential to solve both the challenges of production, transport and storage by producing hydrogen gas "in-situ" using solar irradiation [15].

To the uninitiated in the field of graphene, it is an allotrope of carbon. It is a 2D arrangement of carbon atoms in a hexagon. Graphene, if we are able to manufacture it at a very large scale [16], seems to have the potential to be the panacea for a huge majority of problems plaguing mankind. From structural industry to drug delivery systems, aerospace to semiconductors, graphene has found an application in every field

In 2017, a team of PhD students successfully conducted an experiment in which, the team was able to direct the motion of graphene membranes by using only light in a micro-gravity environment [17]. This has a potential for graphene to be used as solar sails, analogous to sail boats but for space travel.

One of the challenges in developing membranes is the trade-off of between membrane strength, thickness, maintenance costs (due to fouling and concentration polarization, pore size distribution and throughput. Graphene, due to its inherent strength can sustain high pressures hence high throughput. A group at MIT has shown that graphene with precisely controlled pores has the potential to purify water with manifold efficiency that current methods [18]. Graphene based membranes have also found use in dialysis and biomedical separation [19].

Using graphene, a research group from Centre for Nanotechnology at IIT Guwahati has developed self-propelling micro-nano bots whose motion can be induced and directed using different field gradients such as pH, pressure, electric field and magnetic field [20]. Inducing motion via magnetic field gradient has also shown to be possible in surfactants whose cation has been replaced by a magnetic metal such as Fe^{2+}. Micelles of such surfactants have shown to be influenced by magnetic field [21]. Such have a huge potential in targeted drug delivery and separation processes.

A group at Manchester University is dedicatedly working on molecular level machines, developing molecular motors, assemblers and knots [22]. Inspired by nature's molecular machine found in every cell – the ribosome which tirelessly produces proteins and polypeptides with an accuracy and precision beyond 6 sigma, the group has built an artificial molecular machine which can build chemical structures the same way this seems straight out of science fiction, a molecule to make a molecule. A nano-factory where the "worker molecules" synthesize various complex chemicals with extremely high precision [23]. And this need not be forever a part of fiction, because nature has already built nano-factories in every cell ! It is only a matter of time that human learn to mimic nature and built the same for ourselves. Nature is indeed the best teacher [24].

In this article, we looked at a few inspiring technologies being developed around the world. From manufacturing, microfluidics, point of care diagnostics, smart materials and polymers, graphene, smart "chemicals". This list is by no means exhaustive. It was only due to paucity of space and time that only a fraction of such innovations could be described here. The reader is encouraged to go through the references of the technologies mentioned here for more information.

Note: Rather than referring the reader to the original paper or patents, I have given the official website / video links for easier access to the multimedia and overview of the technology. A reader interested in the technical aspects is encouraged to kindly go through the original paper and patents.

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Guwahati Regional Centre Activities

Seminar Series on *Evaluation of Physical properties by acoustic resonance phenomena for porous food materials*

Prof. Takahisa Nishizu, GIFU University, delivered this talk on October 23, 2018.

For porous foods such as breads, sponge cakes and whipped creams, their qualities depend on porous properties such as "bulk density" and "texture". However, appropriate method of quantifying them is not well known. We have proposed a novel method for measuring volumes and porous properties of foods by using Helmholtz acoustic resonance phenomenon. In this study, a Helmholtz resonance technique was employed to predict the airflow resistance of layers of granular materials, namely glass beads, brown rice, soybean, adzuki beans and corn kernels. Each granular sample was placed on the tube mouth of an open-type Helmholtz resonator. The resonant frequency was determined by measuring the electric impedance of a loudspeaker that was installed in the resonator and driven by a chirp signal linearly sweeping from 90 to 220 Hz for 6.0 s. For a changing sample layer thickness, the resonant frequency was measured, and the specific airflow resistance was calculated by measuring the static pressure drop required for N2 gas to flow through the layer at a constant velocity of 0.042 m/s. When the thickness of the layer was fixed, the Helmholtz resonant frequency decreased as the specific airflow resistance increased, regardless of the kind of granular material.

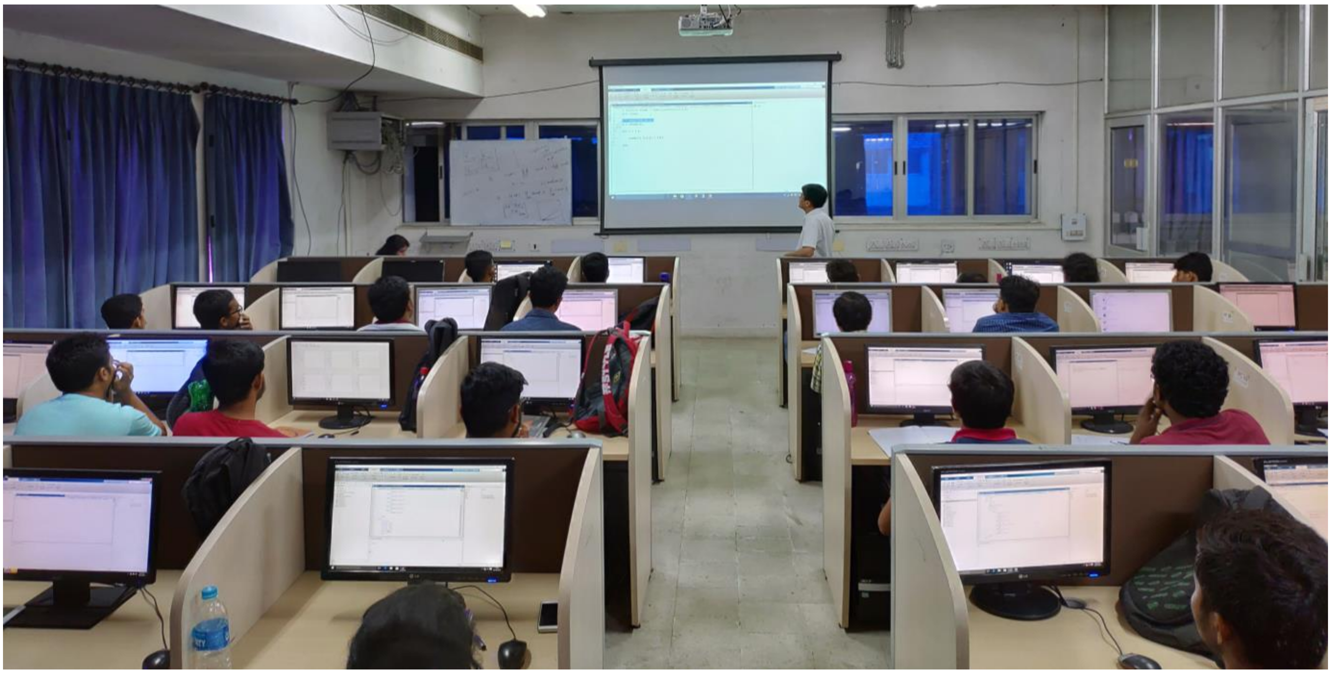
One day Workshop on Computer Aided Advanced Applied Optimization

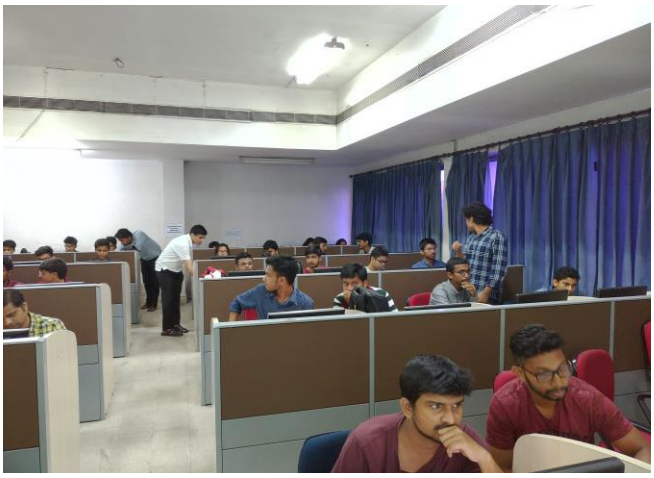
The Department of Chemical Engineering, IIT Guwahati and the Indian Institute of Chemical Engineers - Guwahati Regional Centre organized a workshop on Computer Aided Advanced Applied Optimization on October 6, 2018 . The workshop covered multi-objective optimization techniques and case studies of everyday engineering & management problems.

One day Workshop on Applied Optimization

The Department of Chemical Engineering, IIT Guwahati and the Indian Institute of Chemical Engineers - Guwahati Regional Centre organized a one day workshop on Applied Optimization on October 7, 2018. The workshop included a hands-on session on the optimization toolbox of MATLAB. In addition, algorithms which have been recently reported in literature (and not available in MATLAB) were also discussed.

IIChE newsletter is available at http://www.iiche.org.in/pdfs/NLVol9.pdf



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