Special Report

Department of Chemical Engineering - WFCFD Workshop

7th International Workshop on Crystallisation, Filtration, Drying, Milling and Granulation ends on a Positive Note

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None can stop the power of an idea whose time has come. This idea could be your key or your competitor's. Having attended the inaugural CFD workshop followed by the second and covered the proceedings; 7th International workshop of its kind, in the series on Crystallisation, Filtration, Drying, Milling and Granulation thrust areas, was organised by the Department of Chemical Engineering in conjunction with World Forum on 21-23 February 2013 at K.Venkataraman Auditorium. **T**he objective was leveraging unit operations for chemical and allied Industries growth and showcasing case studies with a view to bridge the gap between practitioners and researchers in the institutes of this country and all over the world, and to cater to the needs of the industry.

Success by Design - Success is rarely achieved by accident. Prof J.B.Joshi (former Director of ICT) is a reflection of the foresight, excellence and dedication that embody success. He had delivered plenary lecture on Computational Fluid Dynamics: Understanding of physics of turbulence and design of novel equipment with focus on successful case studies in commercial practice. This was followed by renowned speakers in the above areas, which were attended by delegates comprising chemical engineers, plant managers and R&D scientists from chemical and allied industries such as pharmaceuticals, food, specialty chemicals and the others who handle solids besides faculty, staff and students. It was also a meeting place for business interaction and strategic alliances. Exhibitors showcased their products and services and industry sponsors extended their support. Excerpts:

Prof B.N.Thorat welcomed the delegates and distinguished speakers from overseas and India and convened the proceedings. Regarding equipments, they endeavour to come up with best in design depending upon certain principles, ideas and economy. This was the focus for the industry-institute-equipment manufacturers who came together on the same platform and shared their potential experience in the field for further development.

Prof A.S.Mujumdar, Mechanical Engineering, National University of Singapore, a pillar of strength for the activities at ICT, appreciated the dedication, passion and hard work of Prof Thorat since more than a decade and gave background of the workshop in his opening remarks. Drying is a fine discipline, not recognised as critical when they started and embarked on the idea of a series way back 1978 since oil and hence cost of energy was cheap until such time the scenario changed. Subsequently, Crystallisation, Filtration (particularly in pharmaceuticals) and Drying combination assumed importance for propagation with university-industry interaction and globalisation.

Chief Guest **Mr.Thomas Mathew**, President - PTA & Gasification, Reliance Industries Ltd extended support from inception in 2001 followed by symposium in 2004. Prof J.B.Joshi has been a mentor since beginning and Vice-Chairman Mr.Mukesh Ambani was a student of this premier institute. He has been working for Reliance since 27 years and with the subject close to his heart, he developed relationship with ICT and recalled his exposure to ammonium sulphate production entailing crystallisation, filtration and drying. He referred to the Sindri fertiliser plant which was a model in the country, conceived before independence as coal based plant i.e. power plant and raw materials. Coke oven produce gas that was utilised to make ammonia and converted into ammonium carbonate with carbon dioxide followed by ammonium sulphate. While gypsum is a fertiliser, calcium carbonate by-product was used in cement integrated plant.

His job was to set up PTA plant and commission it with Terephthalic acid for Polyester containing the core unit operations and every aspect had to be explored in great detail. The search is on for continuous improvement in process technologies to become world's best manufacturer. Regarding initiative for mooting the idea of this conference, Reliance would always support the venture. Mr.Mathew concluded.

Prof J.B.Joshi (former Director of ICT) a stalwart in his own right having contributed immensely to his area of expertise in building equipment hardware, is an authority in equipment design. When one thinks of a reactor, multiphase system and separation equipment, he is the 1st person who comes to mind. He has established a reputation for himself, the institute and is a walking encyclopaedia. CFDs are difficult operations because the knowledge base is dependent on the design procedures and practices are on appraisal. Most of the energy in industrial practice is spent on drying; and in filtration, problems are liable to occur in selection of equipment, designing and practicing.

Plenary lecture on CFD (Computational Fluid Dynamics): Discussion on understanding of physics of turbulence and design of novel equipment with successful case studies in commercial practice. Energy is supplied to equipment, and in a stirred vessel, energy supplied to the impeller creates clean motion as well as turbulence. Energy should be supplied where needed in an optimal manner by designing the flow and turbulence, only then the equipment can be miniaturised to reduce capital and operating cost. This requires understanding of fluid mechanics and its relationship with turbulence. Thus, making a reactor is worthwhile. The design practice in the industry is entirely empirical. Different types of equipments used in the world are about 400 and are classified into 3 categories depending up on the manner in which energy is supplied. Within crystallisation, there are 11 prominent vendors throughout the world. The objectives could be particle size distribution or shape distribution or morphology. A methodology of design has been developed encompassing 7-step procedure to impart knowledge, expertise and experience. He gave several examples with 7 case studies in order to develop sufficient knowledge and to understand complexity of fluid mechanics and turbulence.

Physics of turbulence is yet an unsolved problem and a major challenge and he explained Annular Centrifugal Extractor. Step 1: Flow visualisation (measurement of fluid flow using equipment like Particle Image Velocimetry or Laser Doppler Anemometry); Step 2: Single phase 3D CFD simulation; Step 3: Validation of measurement against validation of computational fluid dynamics; Step 4: Understanding relationship between fluid mechanics (morphology of crystal) and design objectives (mixing, homogenisation, heat transfer, mass transfer, dispersion); Step 5: Optimisation; Step 6: Separator design or scale up; Step 7:

Implementation. Students should visit industry with data and talk to them; understand flow level and problems in implementation. Learning in the industry while implementing is superior to what one learns in the academic institution. Knowledge of industry is important for an academician as also the confidence imparted by the industry.

Closing thought: We can develop normal equipment designs and processes by understanding fluid mechanics and physics of turbulence. Design the fluid flow, turbulence and attain that turbulence at the location where it is desired. Whatever technology given to industry, problems like load on the environment is solved, projects are assigned to the institution, students get fellowships, overheads are funded by the university and the teacher gets consultation fee. This approach has great potential for a win-win-win situation if sufficient knowledge is developed and design practice is converted into knowledge based practice, Prof Joshi concluded.

At this juncture, Mr.Mathew shared his experience about steadfastness of Prof Joshi and spoke about problems like inadequate conversion with oxidation reactor using para-xylene to terephthalic acid when capacity of the plant increased. Product is solid-liquid-gas and after gathering the data for the 3 phase reaction in the reactor, Prof Joshi commented the capacity could be increased by 25% and subsequently gave presentation to the president and plant engineers. Asked about investment and confidence on the initial work, the Vice Chairman gave green signal to implement it in Hazira plant and when the concerned president enquired on performance guarantee Prof Joshi challenged that if it did not work, he would relinquish his consultancy.

About ICT: **Prof Sunil Bhagwat** gave an overview of ICT saga and attributes, activities and achievements in the chemical engineering department and concept of Exergy (low grade energy utilised in a fruitful way), where not only amount of energy but quality of energy matters. He spoke about the institute from its inception in 1933 with Textile chemistry and Chemical engineering, now grown to 6 full-fledged departments of chemical technology - paint, food, plastics, pharmaceutical, pharmacy, dyestuff etc. The institute transformed art into technology and in turn to engineering to science. This is the only institute in the country offering a degree in dyestuff technology and much of the dyestuff industry owes its origin to the institute. A survey by IIM a few years ago revealed that 42% of chemical and allied industries turn to ICT for their needs. 1000 undergraduates, post graduates (400) and PhDs (700) supported by 79 faculty members is unparalleled by any institute in the country besides largest number of PhDs in engineering and chemical science. Number of PhDs per faculty on an average is fairly large with the record that the first ever PhD in engineering graduated from here. The networking resource centre is geared at generating human resources besides helping other institutes. Department of Atomic Energy partnered with ICT for development work e.g. Heavy water. About 20 projects are ongoing on at any time.

Home Paper Project encompass students starting with literature survey on product and process for manufacture, selection, process flow diagram, design integral equipment, costing, layout and finally come up with a viable project report, which may be used by a company for going into production or not. In the process, students exercise whatever they have learnt in chemistry, physics, chemical engineering, material balance, energy, unit operations and thermodynamics, and virtually showcase the subject they know. ICT has a track record of scoring the prize for the best home paper of the undergraduates from Indian Institute of Chemical Engineers. Some of the courses widen the horizon of the students' knowledge to pursue management and research for enhancing technology. The thrust is R&D, curriculum development in a continuous way and revised course with changes effected in structure and content. Research publications of 70 in 2003 enhanced to 111 in 2012 besides filing patents. Fields of research are process intensification, energy engineering, separation processes, operating technology and computational fluid dynamics, organic process development, membrane-based separation, cavitation phenomenon, solar chemistry, new developments in catalysis etc. While nanotechnology and biotechnology with research funding are the future; energy, sustainability and material science have always been the subjects here. It is amazing what chemical sciences have contributed to the world and posters to this effect were on display in the department, Prof Bhagwat concluded.

Industrial Crystallisation

Prof Ka Ming NG, Dr.Christianto Wibowo and **Dr.Ketan D Samant** with a background in applied thermodynamics, separation and reactive separation processes, crystallisation, solid liquid equilibrium and phase diagrams, shared the platform and spoke on fundamentals of crystallisation interspersed with handling of various industrial problems.

Speaker	Location	Topic
Prof Ka Ming NG Hong Kong University of Science and Technology	Dept of Biomolecular Engineering, Consortium of Chemical Products and Processes	Crystallisation process development: A thermodynamic-based integrative approach; Industrial Crystallisation - Case Studies
Dr.Chriastianto Wibowo Group Manager, Principal Engineer	Clearwaterbay Technology, Process Development Company	Design of crystallisation experiments & data analysis; Development of crystallisation & solid handling process
Dr.Ketan D Samant Group Manager, Principal Engineer	Clearwaterbay Technology Process Development Company	Design and Development of Crystallisation Process

Prof Thorat remarked that maintaining super saturation and crystallisation pattern within the narrow globule and saturation curve or between super saturation and saturation curve for maintaining crystallisation, is a challenge.

Industrial Filtration and Granulation

Speaker	Location	Topic
Dr.Ingolf Voigt Environmental Engineering and Bioenergy	Fraunhofer Institute for Ceramic Technologies and Systems IKTS, Hermsdorf Branch of the Institute, Germany	Ceramic membranes for water purification product cleaning and solvent recovery; Inorganic (Zeolite) membranes for dewatering of organic solvents including bioethnaol
Mr.Shripad Khatav Managing Director	S.S.Techno Services Private Limited	Multiple effect evaporators for zero liquid effluent discharge
Mr.Kishor Makvana, MD	Rotofilt Engineers Ltd	Solid-liquid separation
Mr.Andre Adam Global Account Manager	Siebtechnik GmbH	Principle & Practice of solid-liquid separation: industrial centrifuge&decanter Batch and Fluid bed drying - Experience in handling several industrial applications
Prof Jim D Lister Professor and Director University of Purdue	Chemical Engineering, Industrial and Physical Pharmacy	A mechanistic understanding of wet granulation; Multiscale design models for continuous agglomeration process for delivery form manufacture

Dr.Ingolf Voigt spoke about use of ceramic membranes for MF, UF and NF for applications like water purification and waste water from textile industry (chromophors/organic dyes degradation), product cleaning, (Quinoline extracted from chicory in n-Methyl-pyrrolidone by diafiltration incorporating UF membranes to remove salts or other micro solutes from a solution), solvent recovery, and organic solvent nanofiltration. Efficiency of bioethanol production can be improved by implementation of membranes.

Mr.Shripad Khatav: Chemtech Foundation awarded them star SME, Best green technology SME and innovation for contribution to multiple effect evaporators. He highlighted the art of Zero Liquid Discharge for industrial effluent using evaporators and the concept that not a single drop of liquid effluent discharges out of industrial premises. Evaporation is the separation of liquid (water/solvent) phase using (thermal) energy. From economic point of view, zero liquid discharge plants are not productive owing to the energy that goes into operation depending upon the fuel (diesel, biomass, coal) used for steam generation. Waste products are pulp effluent (from bagasse) - sodium lignosulphoanate; ammonium sulphate, molasses etc. Effluent treatment plant (Reverse Osmosis/Ultra Filtration etc) criteria were pH, TSS, TDS, COD, BOD, Color, Temperature and Precipitation etc. Field of applications featured were chemical and allied such as pharmaceuticals, distillery, pulp and paper, dyes and paint, textile, electronic hardware etc. A condensate sample of water obtained from MEE containing few thousands of COD (treatment yet required for drinking purpose) was exhibited.

Mr.Kishor Makwana a mechanical engineer and trained in BARC considered solid-liquid separation as an ice-berg. Filtration is a bottleneck if the equipment is not balanced properly thereby reducing profit apart from the other factors like increasing cost of energy, drying, manpower and maintenance. How to enhance or retain profit? The answer is energy efficient equipment, equipment to deliver optimum moisture and control room operated equipment. Mechanism/components of solid-liquid separation are three fold - mechanical, chemical and chemistry. The mechanical part concerns equipment manufacturer and the other two are in the area of end users. Equipment is of 2 types, either decantation or filtration. Process is the chemical i.e. particle size, viscosity of liquid, density of solid, liquid mixture, concentration, nature and behaviour. Change of particle size governs rate of filtration. Chemistry concerns compatibility, and suitable material of construction. Liquid, solid porosity and quality - quality changes, efficiency of separation also change.

Decantation is done by gravitational force (clarifier or pre-thickener) or centrifuging force. Filtration is done using vacuum or centrifugal force or pressure in either continuous or batch equipment. It is automatic vertical pressure, rotary pressure filter and filter press. Filtration or separation is a bottle neck in production. Media is cloth, paper, screen etc. To accelerate the process of filtration, apply a force like vacuum, centrifuging, pressing and this ultimately leads to ΔP across the cake. Separation efficiency is ΔP and time. Vacuum ΔP 1 bar maximum, pressure up to 16 bar. ΔP and time is a function of dewatering. Separation efficiency depends up on ΔP across the cake, retention of the cake, and cake height. Competitiveness of production process is determined by performance in terms of cost, quality, productivity, safety, health and environment. Filtration has a role in deciding the competitiveness of the process plant. With indepth knowledge of the hidden factors, one can optimise his choice in process design, equipment selection, and process optimisation that creates and sustains competitive advantage.

Ishikawa diagram (filtration process performance) illustrates Slurry filterability, media used, equipment design, maintenance, installation, operation (equipment to equipment). Case studies of materials: Diamino Stilbene Disulphonic Acid (pH 2.5, temperature of slurry 90ºC) - Agitated Nutsche Filter vs. Automatic Vertical Pressure Filter; H-Acid - Vacuum Nutsche vs. AVPF and CEFFG - centrifuge vs. AVPF.

Mr.Andre Adam gave an exhaustive overview of centrifuges and decanters in solid-liquid separation under centrifugal force - basics and implementing technology, types of centrifuges - how to choose the right centrifuge, particle dewatering, dewatering in decanter-centrifuge, Siebtechnik range of centrifuges - sedimenting, filtrating, hybrid, lab test in different applications e.g. ammonium sulphate, mixed salts, polymers etc.

Prof Jim Lister is an authority in granulation technology and an Invitee to Prof A.S.Mujumdar Distinguished Visiting Fellowship Lecture. Prof Mujumdar spoke about the Fellowship that was offered to industrial processing operations like drying and later extended to filtration, crystallisation and now granulation. Industry-University interaction is unique at ICT with industrial connection for transfer of knowledge and technology to industry.

Prof Lister said that wet granulation is more of an art than science and spoke on understanding of wet granulation, mechanism of physics of process and usefulness to engineer or technologist; key mechanisms and dimensional groups that control, followed by granulation rate processes and application (pharmaceutical) as case study on twin screw continuous granulation. Nucleation process entails addition of liquid to dry powder to form the initial granules on distribution of the liquid. Agglomeration is process of coalescence of particles. Consolidation and growth - the key formulation properties of liquid content, stress and liquid viscosity, the key process formula is a characteristic collision velocity, which is related to process equipment followed by concept of using regimax and dimensional groups to characterise process and control formulation. Case study was discussed using this concept. Summing up, he said that deconvoluting the rate process within a granulator that controls granulator attributes make sense of a difficult to understand unit process, and to do this, careful characterisation is needed of both the formulation and process; regime mapping is useful in trouble shooting and scale up.

Prof Lister in his second lecture spoke on application to fluidised bed granulation, Twin Screw Granulator, Equipment built for extrusion in order to do continuous wet granulation. Continuous granulation (process monitoring) with wet granulation; Granulation processes - nucleation, coalescence, effect of binder process, consolidation and attrition. With continuous granulator, residence time of few seconds (10) relatively ease away, capture size distribution of the liquid leaving the granulator. Process control for continuous process integrated back to crystallisation is the future i.e. integrated control for continuous manufacturing system. Continuous processing needs pharmaceutical applications. Active discussions with delegates followed in and through the presentation.

Closing thoughts: Primary particle properties are important in determining downstream delivery form processes and product attributes; Multiscale and compartmental approaches develop predictive design models for granulation processes; Continuous granulation offers significant potential improvement in both design and operation; Integration of continuous manufacture through to delivery form is the future.

CFD - Case studies: Based on observations while handling some problems, **Prof Thorat** discussed some case studies in detail like Recrystallisation in spherical form; Crystal properties: influence on filterability; Filtration and drying of Polymer Hydrogel - Phosphate binding drug; Sludge drying; Screw conveyor dryer and other applications; Reducing the moisture content from 12% to < 1% and simultaneously reduce the particle size from 200 µm to 45µm.

Milling and Industrial Drying

Speaker	Location	Topic
Prof Sunil S Bhagwat	Institute of Chem Tech	Overview of ICT and Dept of Chem Engg
Prof A.S.Mujumdar National University of Singapore; EDB	Minerals, Metals and Materials Technology Centre; Faculty of Engg	Drying technology: An overview - Fundamentals, Classification and Selection: Recent advances
Mr.Michael Kuhnen Senior Sales Manager	Hosokawa Alpine AG Pharma Lab Division	Milling and Micronising in Pharma inds; Milling process and product performance
Dr.Peter G.J.van der Wel Manager R &D	Hosokawa Micron B.V Process Technologies	Advanced Drying Technologies
Mr.Surendra H Shah, MD	Panasia Engineers Pvt Ltd	Low Energy Heat Pump Air Dryer
Mr. Edward Wozniak Sales Manager, UK	CPM Wolverine Proctor	Batch and continuous conveyor dryers / Fluid bed and impingement technology
Mr.Peter Zagorzycki Senior Applications Engr	CPM Wolverine Proctor	Basic of air drying concepts
Mr.B.B.Gatkal	Promos Engineers Pvt Ltd	Drying under Vacuum
Dr.Sachin Jangam	NUS, Singapore	Energy Saving Strategies in Drying

Prof A.S.Mujumdar: An institute by himself and soft spoken, he wanted to be present at the ongoing CFD Workshop at his alma mater in Mumbai and suggested to Chinese government that the honour being bestowed on him (a title equivalent to our Padma Awards) on 22nd February for his contribution in this area, be sent to him at his residence address in Singapore. Graduated in 1955, he did PhD under the guidance of Prof Douglas at McGill University, Canada and continued working on Drying and the rest is history. Of late, he has been disseminating technical literature open in e-books form (spray drying, mathematical modelling, solar energy, fluidisation) on his website (environment, energy, drying technology, mass transfer) which also includes his collaborators work.

Starting with introduction to drying, he covered fundamentals (basic terms), why so many dryers (complex process), key criteria in classification and for dryer selection, types of dryers, energy related issues, innovative techniques, limitations etc. Removal of a liquid from a solid/semi-solid/liquid to produce solid product by thermal energy input causing phase change (sometimes converts solid moisture into vapour by sublimation). Energy input by thermal drying e.g. indirect (conductive), convective (direct), radiation (natural drying in the sun), microwave and radio frequency fields, and while drying particles, moisture output by liquid or vapour diffusion, capillary flow etc. Typically, drying is a terminal step that decides the final quality and any error made is not safe. Diffusivity is a function of moisture and temperature. Liquid diffusion is most common for low temperature drying (below boiling point). Under vacuum drying boiling point goes down to 40ºC. Drying is a complicated process. Properties of material like porosity may change. Drying of super gel is typical and shrinkage may be a problem besides change in quality like color. And for foods, retaining flavour, smart dryer is proposed.

Adiabatic saturation temperature, a thermodynamic entity is a gas temperature and the liquid temperature depends on kinetic heat and mass transfer rate. Zero moisture (difficult to measure) requires enormous amount of energy and it cannot be accessed since it is bound tightly as monolayer to the solid. Free moisture can participate in terms of diffusion model. When surface moisture has gone, then the moisture has to transport from interior to surface and there is a resistance to mass transfer and heat transfer. This point is critical moisture content. Diffusion model is regression and is a differential agitator. Diffusivity is empirically determined as a function of moisture and temperature. In a dryer, the drying conditions change, the equilibrium hasn't changed while premoisture is changing continuously. Newspaper drying is typical due to various factors like diffusivity and thickness. Paper is an active dehydration and it takes 1 kg material and adds 200 kgs water and gets rid of water. In a combination of dryer and material, it is not the dryer that decides the design and operation. Drying time for the same material depending on the productivity, one can use different dryers. In some cases, drying time and cost is not due to dryer or energy but inventory cost. In some cases, emerging economies use better technologies than developed countries. Some products have gone beyond such a scale making innovation in these areas difficult since they are expensive and risky.

Why select dryer? Some pharmaceutical companies in Europe several years ago identified that dryer selection as main problem facing industry and it is cumbersome amongst so many dryers available and consequently lost production which is more than the cost of dryer itself. Hence, know your product, process and characteristics before selecting the proper dryer rather than at random e.g. spray dryer, fluidised bed, flash dryer, rotary dryer etc since performance and costs are different. Flash dryer is best option which is cheapest and best.

Mr.Michael Kuhnen gave an overview of different types of mills (impact, classifier, spiral jet, fluidised bed opposed jet, wet agitated ball mill etc) which are available and their selection in specific application with size reduction (design factor and product design function) and its theory followed by details of the overall milling process and size of the milling equipment. Layer of thickness is dependent on pigment particle size distribution in the paint surface, change of colour by change of particle size of pigment; taste of food ingredients by particle size and flue gas desulphurisation etc. Factors in designing milling process are energy, product cost, labour, cleaning, downtime, maintenance cost, safety of product and operator and investment. Milling energy and its optimisation; Intelligent Process Control - case studies were discussed viz. Global Pharma Company - Pharma multi process concept/system and Fish Feed Industry - Pea Protein shifting.

Key issues while selecting and designing a milling system, one has to consider material properties (brittleness, hardness) that influence size reduction thereby the selection of right milling equipment with reference to size reduction principles, milling technologies and application areas. Milling dry powders, type and material properties influence selection of right milling equipment (depending upon coarseness to fineness, microns, nanoscale).

In summary, product function needs to be fully understood, Fineness requirement has to be defined carefully; Selection of right milling equipment (two different parts of the mill with the same product with different energy can be used differently), Condition of the milling process has to be carefully evaluated; Analyse and understand process cost structure of milling; Investment is mere 5% of the overall cost and the process cost structure for durable process application; and Design customised system layout, Mr.Kuhnen concluded.

Mr.Surendra Shah a mechanical engineer specialising in air conditioning and application, young at heart, a role model whose age (80) is no barn for fresh ideas, Mr.Shah is an expert on energy efficient system and works with passion. When air is cold heating involves expenditure. So they entered the area of low humidity and low heating products with low energy. Contrary to early 60s, the target now is low operating cost and the low energy heat pump is a logical choice since one kilowatt input to a heat pump gives almost four kilowatts of heat into the air as against direct heating which delivers one kilowatt of heat to the air.

The principle is removing the cold air from the evaporator, which also removes moisture from the air; low energy dryer uses evaporator as a front end, so that the leaving air has lower moisture content. Thus it can remove more moisture at any given temperature when compared to heated ambient air. More moisture can be absorbed by air at the same temperature if it is drier. The low energy heat pump provides both heating and cooling functions, the total C.O.P. is 6.7 (combined drying and cooling). Mr.Shah concluded his talk displaying a couple of commercial samples like turmeric (haldi) for aroma etc.

Mr.Peter van der Wel: Hosokawa has all disciplines from engineering, manufacture, assembling and installation; Technology centre for mixing, drying and agglomeration. Wikipedia defines drying as a massive transfer process consisting of the removal of water or another solvent by evaporation from a solid, semi-solid or liquid. This process is final production step before packing or selling. The ultimate product must be solid, in the form of continuous sheet (paper), long pieces (wood), particles (cereal grains or corn flakes) or powder (sand, salt, washing powder, milk powder). He discussed basics of drying solids, choosing a vacuum dryer, vacuum drying systems and future in vacuum drying, developments in active freeze drying. Selection of a dryer is made with reference to product, process and application (pharma, food and chemical). Drying: mechanical - centrifuge, filter press, sedimentation and Thermal - radiation (sun), convective (hot air)) and conductive (indirect, heated wall). Freeze drying is to dry difficult materials such as thermo sensitive solids; fragile materials, structured materials; ultrafine powders. Dynamic freeze drying conditions result in benefits like easier handling, faster processing, better product quality (bulk density, particle size distribution, colour, taste, appearance, dispersibility, survival rate, crystal structure).

Mr.Edward Wozniak: California Pellet Mills (CPM) Wolverine Proctor serving customers, employees and investors since 1883 world's leading process equipment supplier for animal feed, oilseed, biofuel, extrusion and thermal processing applications. Designing, manufacturing, and supplying dryers since 1894 for fibre, rubber, chemical, tobacco and food. He spoke about continuous invective drying. Dryer is a costly piece of equipment and incorrect selection of dryer may be catastrophic. Features, market size, benefits of designs, drying characteristics and applications were outlined.

Mr.Peter Zagorzycki presented technical information of products, processes and precision-engineered equipments and expressed that technology is not so apparent in machinery itself and it is experience in material handling, drying process details and sizing energy. Product temperature within the range through the dryer is of interest. Once the drying sets on the surface and enters into the particles, the mechanisms are capillary action, diffusion etc and the product itself starts influencing the behaviour of evaporation and the more energy it takes, more rapid the drying rate. He spoke about mass transfer, classic drying curve, limitations in design, and other considerations like related drying parameters, effect of humidity, psychometric chart; typical conveyor dryer cross section, energy consumption versus operating temperature, temperature versus humidity, sizing a dryer, preliminary drying operation, extrusion of filter cake, dryer sizing rationale, test sample, selection, quantity, transportation, preparation, test and laboratory equipment, variable circulation laboratory dryer, conveyor sticking/binding, ease of dump, typical test drying curve, basic sizing, product feed, machine, variations, test conditions, single conveyor dryer, two stage dryer, typical 3 stage SCF dryer, multistage dryer, multi conveyor or multi deck dryer (MCD), conveyor dryer. Textile processing, perforated drum dryer, energy-usage example, specific steam consumption, cost effects of operating dryers, design capacity, humidity control system, exhaust, heat recovery from exhaust, incinerator; fluid bed drying and impingement technology, jet zone fluidisation, air velocity sufficient to reach the conveyor base, typical fluid bed cross section showing air system, options, dust particles filtration, cyclone, non fluidised product configuration, bake oven, typical application pizza, double impingement oven, rotary batch, pilot plant etc were also discussed.

Promos Engineers manufacture process equipments (agitated vacuum dryers) and cater to various industries. In vacuum technology, they have a range of vacuum dryers. If we reduce down to size a product, the heat transformation or drying would be faster as in agitated vacuum dryer for drying heat or air sensitive products. Lump breaking equipments reduce the size of lumps formed in agitated vacuum dryer. The advantage is short drying time. Equipments are available in various sizes from 5-2000 litres.

Dr.Sachin Jangam spoke about energies used for industrial drying; techniques for energy saving, new drying techniques. Drying is highly energy intensive operation due to various factors. Water has high latent heat of vaporisation, affinity of solids to water, bound water requires extra energy for removal from solid or hygroscopic material, difficulty to supply heat at a particular location where the moisture is because moisture has to diffuse to surface before it is evaporated. Use of higher temperature has limitation with heat sensitive products. Options to save energy: drying cannot be avoided in case of food and pharmaceutical products; displace water with solvent like dimethy ether (DME) having low heat of vaporisation and high vapour pressure but the problem is separating water and solvent mixture. Use mechanical means like filtration, ultra-centrifugation to reduce the load on drying besides economy, or use evaporator for liquids.

National energy consumption in developed countries is 5% of energy used for thermal dehydration. In Canada, thermal dehydration is 250 Pj per year and 19 million tons of CO_2 and similar amount in UK, which are high. According to Good Manufacturing Practice, 70% of total energy used is just for drying. It is also applicable to textile, paper and pulp industries. More the energy used more the carbon emission. For pharmaceutical and specialty food products drying, quality is most important but attention is not paid to drying or energy used. Therefore energy efficient drying is of paramount importance. Of industrial drying systems used, one can see that a typical energy efficient dryer is 40-80% e.g. rotary (50-60%), similarly spray dryer, fluid bed dryer (40-70%). Actual efficiency ranges from 20-40% due to improper operation (high temperature or velocity); improper application (existing dryers used for other products), improper design. Some dryers are built in-house with inadequate knowledge and lack of proper insulation. One has to look for basic drying characteristics, drying system and not just dryer. Use mechanical dewatering as far as possible. The overall strategy is pre-drying (mechanical dewatering) and post drying (cooling, granulation, blending) to save energy. Mechanical dewatering is cheaper than evaporation, which is cheaper than drying.

Techniques for energy savings: How is energy produced for drying? Direct firing is most efficient, electrical heating technology (expensive) yields highest quality of heating and removes the moisture by vacuum. New technologies are infrared drying for surface heating. Heat recovery - recycle of gas or heat pump to recover energy. Control of dryer and new developments like superheated steam. For improving energy efficiency of drying, replace old dryers with advanced technologies or use multistage dryers and hybrid technologies. Directly reduce the dryer heat duty, by reducing the inherent requirement for drying (mechanical dewatering) or by reducing heat losses or batch time. Reduce the cost utilities or primary energy requirement by use of low-grade heat; combine heat and power, cogenerate heat and power while supplying the heat required to the dryer; heat pump to recover waste heat to provide dryer heating. Energy savings by control: 8-12% achieved when process control is applied (dryers with long residence time) and the conditions required are sensors for moisture content analysis, model for the process, properly designed. Other advantages are control on product quality, increased throughput by control of operating conditions, improved reliability of dryer and reduced labour. Cost of installation of control system varies from $30,000 to 200,000 and therefore cost analysis should be done before using control system. How to save energy in drying - One can use intermittent drying and renewable energy, wherever possible. Do regular energy audits; find out where heat is being lost.

Heat pump drying generates low temperature dehumidified air, which is used to recover heat. The advantages are higher energy efficiency with improved heat recovery, better product (foods) quality, wide range of drying conditions and relative humidity and the limitations are use of CFCs in the refrigerant cycle, which are environment issues. Another system is superheated steam drying. One can use any convective dryer by switching from air to superheated steam; extra steam can be supplied to other unit operations in plant. System should be leak-proof from exhaust. Drying is much faster than conductive drying but only above certain temperature. It is used for drying of lignin (WTA energy efficient process). One can also use multi-staging of dryers to reduce the energy consumption e.g. spray drying followed by fluid or vibrated bed or flash bed to remove surface moisture followed by fluid bed or packed bed or impingement dryer followed by through dryer. Remove surface moisture in one stage and internal moisture in another and have different drying conditions and each stage can be optimised for energy/quality. Pulse combustion dryer is yet another drying system, which is highly energy intensive and efficient. Pulse combustion is intermittent. One can have high temperature as well as velocity. They have high drying rates because of increased turbulence and flow reversal, decreased boundary layer thickness of materials because of turbulence, increased heat and mass transfer rates, high driving force due to high gas temperature, suitable for heat sensitive materials because residence time (short contact time) is few seconds. It has been used even for spray drying. Noise may be a limitation with this drying.

Closing remarks: Incorporate energy-efficiency at design stage; retrofits are possible, may be less ineffective and hence more expensive. You must have good mathematical model to work your controls well. Novel or new dryers can also be used to make the drying system more efficient. Avoid copying flow sheets from elsewhere done at different times and conditions, Dr.Jangam concluded.

Open forums: Questions from the delegates brought the distinguished speakers together who fielded them suitably, cleared misconceptions and offered advice. Prof Arun S Mujumdar, Mr.Andre Adam, Mr.Michael Kuhnen, Mr.Surendra Shah, Mr.Peter van der Wel, Mr.Edward Wozniak, Mr.Peter Zagorzycki chaired the panel discussions on the final day. Prof Thorat proposed vote of thanks to the distinguished speakers, delegates, sponsors and student volunteers for making the conference a success.

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