Combustion science*

Following the four successful workshops on combustion science held earlier[1–3], the theme for the fifth workshop was centred around missile development-related problems, while preserving the variety in the nature of problems in combustion science. The workshop was inaugurated by the Director, Defence Research and Development Laboratory (DRDL), Hyderabad. It had 21 presentations on novel aspects related to solid propulsion, high-speed air-breathing propulsion, liquid jet breakup, combustion instability in gas turbine afterburner, fire research, premixed flame dynamics, biomass gasification, microcombustion, high enthalpy flows and other combustion processes. The specialty of the workshop was that the participants numbering around 100, including about 20 students, were shown the integration activities of HyperSonic Technology Demonstrator Vehicle (HSTDV) to be flight-tested soon and the test firing of Liquid Fuel RamJet (LFRJ) engine. A full-scale liquid ramjet engine was also demonstrated during the workshop.

The first talk by H. S. Mukunda (Jain University, Bengaluru) was on quantitative minimalism and scaling laws. Emphasizing the role of scaling laws in combustion science, an example of the behaviour of pan fires and their prediction explored in recent times at Jain University was presented. The simpler scaling approaches as well as more formal methodologies were presented to model the complexities of thermal conduction, Marangoni effects and the formation of convective flows leading to the hot zone inside the liquid fuel.

Bhaskar Dixit (Jain University) presented the study of wind effect reduction for indoor pool fire tests through porous wall configuration. The role of ambient wind disturbances beyond 0.3 m/s was extracted by specifically designed experiments. The new design of a large indoor fire test facility ($12 \times 18 \times 12$ m) using porous wall was studied to understand the air entrainment behaviour of pool fire inside the fire test bay using large eddy simulation-based NIST package of fire dynamics simulator software, and favourable comparisons with experiments were demonstrated. Much discussion on the choice of the porous wall design followed.

There were seven talks on solid propellant combustion. P. V. G. Brahmanandan (Advanced Systems Laboratory (ASL), Hyderabad) spoke on present issues and future requirements of the design and development of solid rocket motors for various strategic and tactical applications with burn times from a fraction of a second to 110 sec, thrust levels from 250 kg to 90 tonnes, diameter from a few tens of a millimetre to a few thousands of a millimetre, and propellant mass from a fraction of a kilogram to a few tens of tonnes. The new technologies required to improve volumetric loading, rocket motor mass fraction and ageing characteristics were highlighted.

R. Srinivasan (ASL) presented applications and challenges of pyrotechnics, pyro mechanisms and explosive ordnance, and highlighted the advantages of its uses in spacecraft, underwater vehicle systems, launch vehicles and missiles, where weight is at a premium. Typical examples of rocket motor ignition, stage separation, fairing release, location aids, time-delay trains and command destruct systems were presented. High reliability, life and functionality in extreme operational environments were considered a major challenge in the development of these systems.

Pandu Karanth (DRDL) presented the development of pulsing technique to demonstrate the combustion stability of solid rocket motor. He explained the experience of mild to severe oscillations, with significant shift of the mean pressure and higher harmonics of rocket motor chamber pressure in tactical systems in longitudinal modes. Pulser technique that was specifically developed for this project to suit the motor configuration was used extensively to demonstrate the solid rocket motor stability.

Arvind Kumar (High Energy Materials Research Laboratory, Pune) presented the need for nano-diamond synthesis and 3D printing to develop efficient solid propellants for defence and space applications. He also mentioned the advantage of using 3D printing process in the casting of composite propellant. In an answer to a query, B. N. Raghunandan (Indian Institute of Science (IISc), Bengaluru) clarified that samples of composite propellant have already been made using 3D printing technique at IISc.

Souraseni Basu (DRDL) presented numerical simulation using large eddy simulation for a motor port configuration with deep circumferential slots, since it was found that there were significant unsteady pressure oscillations. It was also observed that due to significant blockage near the exit of the nozzle, new aerodynamic throat is produced upstream of the geometrical throat leading to oscillations. Change in geometry to remove the aerodynamic throat allowed reduced rocket motor pressure oscillations significantly.

K. Gnanaprakash and S. R. Chakravarthy (IIT Madras) discussed the unusual burning rate trends of certain nano-aluminized composite propellant formulations through sandwich combustion, using high-speed, high-magnification imaging of combustion of sandwiches (made of alternating laminae of ammonium perchlorate (AP) and a matrix of hydrocarbon binder mixed with fine AP and nano-aluminium particles) in the 1–12 MPa pressure range. The lamina leading edge flames are seen to control the burning rates of the sandwiches even in the case of fast burning matrix that contains nano-Al.

Nagendra Kumar and P. A. Ramakrishna (IIT Madras) presented experimental and computational studies on the effect of ignition on low pressure deflagration limit (LPDL) of AP and AP with additives. It was shown that adding a small fraction of additives/impurities shifts the LPDL of AP drastically from 20 bar. Various intriguing aspects of the experimental observations were sought to be explained through computational studies focused on the effect of incident heat flux on the surface during ignition of AP along with the variation in thermal properties.

*A report on the 'Fifth P. J. Paul Memorial Combustion Science Meet' held on 23–24 February 2018 at Defence Research and Development Laboratory, Hyderabad.

K. Ashirvadam (Gas Turbine Research Establishment, Bengaluru) described the screech instability (high and audible frequency) problems caused due to unsteady coupling between the pressure oscillations and combustion heat release in gas turbine afterburner. Various instability-driving mechanisms like vortex shedding coupled with fuel atomization, vapourization and mixing of large-scale vortical structures from bluff body flame-holders were described. Screech mitigation studies like modification of a perforated liner, ventilation in the V-gutter, and flame-holder modifications were presented. The highlight of the presentation was very high-speed videos of the mixing layer from the V-gutter edges.

S. Varunkumar (IIT Madras) discussed computational approaches to afterburner screech. His study showed that the growth of perturbations follows the classical instability pattern – exponential growth (linear instability) of pressure amplitude of standing wave(s) followed by a limit cycle. The role of bias flow on the pressure oscillations influenced by acoustics-heat release coupling was analysed using computational fluid dynamics (CFD) framework. The work that is now in its early stage showed promise along directions aimed at understanding and resolving the problem in practice.

A. T. Sriram (M. S. Ramaiah University of Applied Sciences, Bengaluru) presented a numerical flow simulation of compressor combustor combined configuration. The computational tool was validated for transonic flow in NASA rotor 37 compressor and can-type model combustor of Tay engine. Three-blade passages of compressor rotor, four-blade passages of compressor outlet guide vanes and about 30° sector of a propane-fuelled combustor with one fuel injector were simulated with k–ω turbulence model and eddy dissipation combustion model. Apart from improvements on individual components through the simulations, they helped in the generation of performance map of the rotary system.

Avijit Kushari (IIT Kanpur) described an experimental programme to study the dynamics of a liquid jet in a swirling flow of air and presented the results. The effect of liquid jet Reynolds number and momentum ratio on jet break-up and primary atomization with swirling air flow was studied under ambient pressure conditions. Further, a range of Weber numbers was considered to simulate the cross-flow in annular passage at elevated pressures. The location of jet break-up, jet penetration, droplet size and velocity at different locations were estimated through detailed visualization with high-speed imaging and tomographic reconstruction and Phase Doppler Particle Analyser (PDPA) system.

Santosh Hemchandra (IISc) presented the studies on coherent unsteady nature of flows with swirl-stabilized premixed flames from the standpoint of hydrodynamic stability analysis. Various shear layer modes – sinuous, varicose, ring, inviscid centre, viscous centre mode – were detected. The influence of flame attachment on the stability of these modes was presented.

Swetaprovo Chaudhuri (IISc) presented the genesis and evolution of premixed flames in turbulence. The mean local flame displacement speed of the leading points was shown to be related to the global turbulent flame speed, with a finite time-lag, and the dispersing flame particles were shown to follow Batchelor's pair dispersion law related to the ratio of generation to annihilation timescales.

The experimental studies on dynamics and performance of a thermal pulse combustor were presented by Swarnendu Sen (Jadavpur University, Kolkata). The influence of inlet geometry and fuel composition on the variation in frequency of operation was examined. The pulsating behaviour was inferred to be due to complex interaction of hydrodynamic (vortex shedding) and acoustic effects. A hysteresis behaviour was observed in both amplitude and frequency for specific cases.

S. Rajnikanth (DRDL) explained the concept of hypersonic glide and fixed point scramjet operation for long-range hypersonic mission. The status of various critical technologies, namely high-lift aerodynamic configuration design, high-temperature materials for airframe and scramjet combustor, descent-phase trajectory and endgame was presented. Rolex Ranjith (DRDL) explained the Dual Combustion Ramjet (DCR) engine which is composed of a subsonic dump combustor, a tandem supersonic combustor and two separate inlets. DCR engine can be used at wide operating Mach numbers (3.5–6.5) and thus enhances the air-breathing mode operation of missile, thereby reducing the overall system weight and making the vehicle capable of air launch. G. Vijay Kumar (DRDL) presented thermal analysis for both airframe and hydrocarbon-fuelled scramjet combustor. Preliminary analysis showed that the hydrocarbon fuel can be used for cooling the combustor with niobium alloy material and silicide coatings. Candidate materials for the remaining portion of the configuration were expected to be C–SiC composites, Inconel, Nimonic alloys and titanium.

Afroz Javed (DRDL) presented direct numerical simulation studies of confined mixing layers of dissimilar gases with large temperature difference pertinent to high speed propulsion system. Two- and three-dimensional simulations were carried out using higher order numerical scheme to understand the structure and evolution of supersonic confined mixing layer of similar and dissimilar gases. The major outcome of this study was that the growth rates of dissimilar gases are affected far more by large temperature difference than by compressibility, and that the growth rates of compressible shear layers formed between dissimilar gases are better predicted using k–ε turbulence model.

Kowsik Bodi (IIT Bombay) presented the two-dimensional finite volume computations of high-enthalpy hypersonic flow over a cylinder and flat plate. The predicted temperature variation along the stagnation line for hypersonic flow (T_∞ = 196 K) over a cylinder and computed velocity profile for a laminar hypersonic flow over a flat plate compare well with the available literature data. Although curve-fit method for thermodynamic and transport properties is computationally inexpensive, composition-based method has the advantage that it can be applied to any mixture of gases.

N. K. S. Rajan (IISc) presented recent activities at IISc in the area of biowaste treatment processes. The injection of superheated steam mixed with secondary air enhances the hydrogen fraction in the producer gas from 18% to 26%, an option for cleaner combustion. The biogas generated from bio-methanation-based treatment plants from sewage and industrial effluent needs removal of H_2S for power generation. Industrial plants were designed to handle H_2S concentrations ranging from 0.5% to 10% to provide clean energy generation of about 4 MW electrical power.

Sudarshan Kumar (IIT Bombay) presented development of single and dual microcombustor-based thermoelectric generator with high power density

(~0.14 mW/mm^3) and conversion efficiency of 4.7% with liquefied petroleum gas as the fuel. The compactness and high output power with significantly improved conversion efficiency appear to have the potential for portable micro-scale power generators for remote stand-alone applications.

One of the important conclusions of the final discussion was that future meetings could be on a theme basis and should focus on the current problems in research and development to make the students aware of the on-going research areas.

1. Shivakumar, V., Ramakrishna, P. A. and Mukunda, H. S., *Curr. Sci.*, 2015, **108**(8), 1412–1413.
2. Mukunda, H. S., Bijukumar and Ramakrishna, P. A., *Curr. Sci.*, 2016, **111**(9), 1440–1442.
3. Mukunda, H. S., Ramakrishna, P. A. and Arvind Kumar, *Curr. Sci*., 2018, **114**(2), 253–254.

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MEETING REPORT

Biodiversity Congress*

The 2018 International Biodiversity Congress (IBC 2018) focused on the theme 'Biodiversity for ecological civilization' through the philosophy of 'Vasudhaiva Kutumbakam'. Over 800 delegates from India and abroad attended the event. The congress was inaugurated by the Chief Minister of Sikkim, Pawan Kumar Chamling, who stressed the need for protecting the Himalayan biodiversity hotspots and suggested an organic India mission by 2050. The event hosted six plenary, ten technical and three poster sessions under six themes. In total, 27 invited plenary lectures were delivered by eminent scholars and 92 papers were presented by the delegates.

In the inaugural session, Savita (Forest Research Institute (FRI), Dehradun) highlighted the importance of biodiversity for sustainable development and emphasized educating people for biodiversity conservation. Vandana Shiva (Founder 'Navdanya', Dehradun) focused on women empowerment and its role in sustainable biodiversity utilization, and underlined the Indian philosophy of 'Aranya Sanskriti'. Rakesh Shah (Uttarakhand Biodiversity Board (UBB), Dehradun) spoke on the transboundary issues and suggested minimizing unmindful developmental activities. Talking about ecological knowledge, functioning of biodiversity, and the impact of climate change on the distribution of species, S. C. Gairola (Indian Council of Forestry Research and Education (ICFRE), Dehradun) shared the efforts of the council for biodiversity conservation and release of REDD+ strategy by the Ministry of Environment, Forest & Climate Change, Government of India (GoI), New Delhi. In a broadcasted inaugural message, Suresh Prabhu, Minister of Commerce, Industry & Civil Aviation, GoI, New Delhi emphasized the role of ocean biodiversity for the storage of carbon and food security. Shyam Saran (Prime Minister's Special Envoy for Nuclear Affairs and Climate Change, GoI, New Delhi) highlighted the lethal implications of unsustainable developmental paradigms and the need for following Mahatma Gandhi's philosophy on judicious utilization of natural resources. The Guest of Honour, Harak Singh Rawat, Minister for Forest and Wildlife, Government of Uttarakhand, Dehradun talked about the deep-rooted culture and tradition of the state in conserving and maintaining biodiversity.

In the first plenary session; while delivering the 'Indian perspective on biodiversity crisis', V. B. Mathur (Wildlife Institute of India (WII), Dehradun) mentioned that out of 52,017 faunal species assessed so far, 17,926 species are threatened. The Gangetic dolphin, dugong, the great Indian bustard and the Manipur deer are on the verge of extinction and therefore need conservation. Highlighting the 'trusteeship' concept of Mahatma Gandhi during his talk on 'Biodiversity education to address sixth mass extinction', Kartikeya Sarabhai (Centre for Environment Education, Ahmedabad) said that a range of eco-friendly practices are promoting more sustainable lifestyles, and therefore their replication could play a key role in biodiversity conservation. Highlighting the ancient traditions and practices of India during his talk on 'Biodiversity – what will persist for future?', K. Venkataraman (formerly at Zoological Survey of India, Kolkata) presented the conservation challenges being faced by agrobiodiversity. Jyotsna Sitling (Ministry of Skill Development and Entrepreneurship, GoI) stressed upon developing skilled human resources to meet the challenges for nature conservation and mentioned the need for upskilling of professionals.

Sharing the pertinent points in 'Convention on Biological Diversity (CBD), Biological Diversity Act (BDA, 2002) and Nagoya Protocol', Rakesh Shah (UBB) highlighted the importance of prior informed consent (PIC) and mutually agreed terms (MAT) for benefit-sharing. Sanjay Molur's (Zoo Outreach Organization, Coimbatore) talk entitled 'Species are in crisis' discussed the conservation strategies to protect 'freshwater conservation points' of different threatened taxa. Balakrishna Pisupati (formerly at National Biodiversity Authority, Chennai) highlighted the importance of brand ambassadors for popularizing biodiversity crisis. M. K. Ramesh (National Law School, Bengaluru) suggested refinement in BDA, which is one of the best Biodiversity Acts globally. On the theme 'Biodiversity, bio-piracy, and intellectual property rights', Vandana Shiva spoke on 'Biopiracy, biodiversity, WTO and corporate control of biodiversity' and shared several success stories with special reference to 'neem biopiracy'. Delivering her talk on 'The Kilta, the cotton, and the Kani – why we need Courts', Prabha Sridevan (Former Chair-person of the Intellectual Property Appellate Tribunal) showed concern on mindless development and its consequences 'Aranyani Hantate', and underlined the need for sensitizing people about traditional

*A report on the International Biodiversity Congress (IBC 2018) organized as a joint initiative of Centre for Innovation in Science and Social Action, Navdanya, Forest Research Institute (FRI), Indian Council of Forestry Research and Education, Wildlife Institute of India, Uttarakhand Biodiversity Board and Uttarakhand Council for Science and Technology and held at FRI, Dehradun from 4 to 6 October 2018.