



IGC Newsletter

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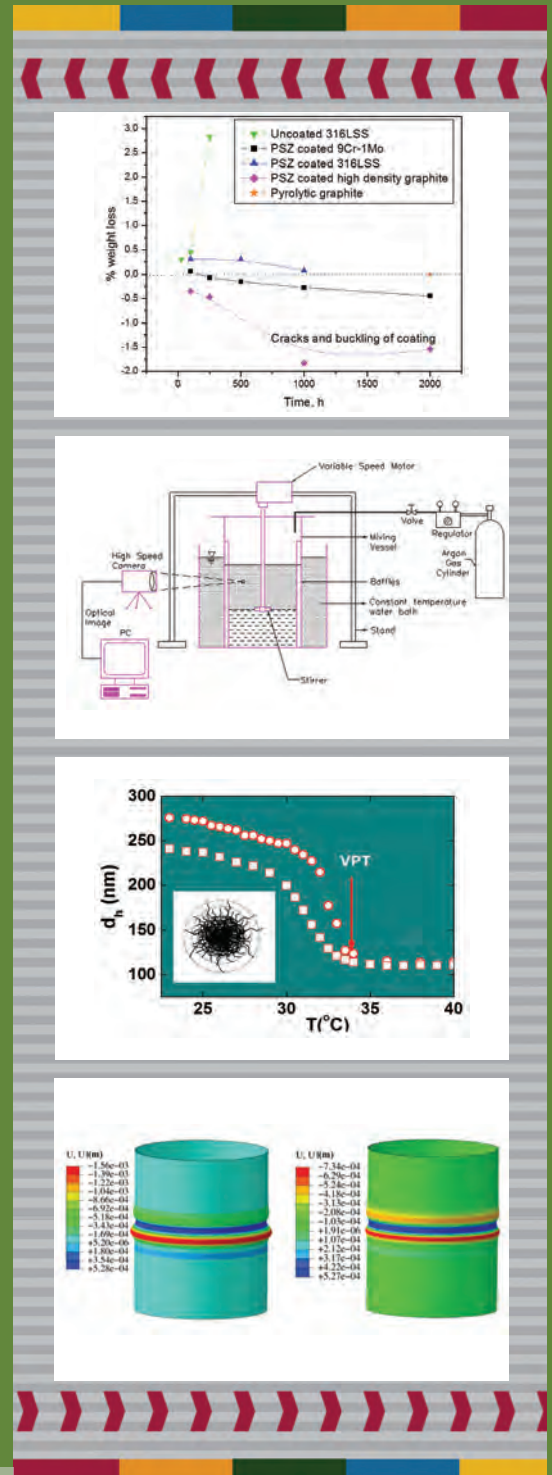
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From the Editor

Dear Reader

It is my pleasant privilege to forward a copy of the latest issue of IGC Newsletter (Volume 105, July 2015, issue).

In the first technical article, Dr. C. Mallika and her colleagues have shared their experience in establishing atmospheric plasma spray and high-velocity oxy fuel spray facilities for the development of metallic and ceramic coating for applications in pyrochemical reprocessing and fast breeder reactors.

Shri R. G. Joshi has studied the influence of soft and core-shell structure of poly (N-isopropylacrylamide) microgel particles on structural ordering, dynamics and shear flow behaviour under dense conditions, and the same is given in the second technical article.

This issue's young officer's forum features an article by Shri Asif Ahmed Bhat on the hydrodynamics of mixing molten salt and cadmium through experimental simulation.

Shri Ashuotosh Mishra has studied the significance of thermo-mechanical constitutive modelling in thermal ratcheting prediction and shared his excitement in the Young Researcher's Forum.

We had distinguished visitors to our Centre in the last quarter including, a delegation from United States Nuclear Regulatory Commission, Prof. Ghanashyam Date, Dr. C. B. S. Venkataramana and Dr. R. K. Sinha.

We are happy to share with you the awards, honours and distinctions earned by our colleagues.

We look forward to your comments, continued guidance and support.

With my best wishes and personal regards,

Yours sincerely,



(M. Sai Baba)
Chairman, Editorial Committee, IGC Newsletter
&
Associate Director, Resources Management Group

Interaction with Dr. Anil Kakodkar



Dr. Anil Kakodkar with the team of Young Officers

Sir, you inaugurated the Training School at IGCAR Campus, this year we have the ninth batch graduating and tenth batch coming in. What is your opinion about the Training School programme, are we fulfilling your expectations?

Regardless of the hard facts on the table, I would like to say yes. The Training School was started by Dr. Bhabha along with the Atomic Energy Programme. If you ask me to identify one single factor for the success of this programme, I would say it is the Training School. So, starting Training School at Kalpakkam was a right step. If you take the Department of Atomic Energy as a whole, each Centre within it has its own programmes cut out. IGCAR is a very large Centre. It is much focused. It is an important research Centre dedicated to the second stage of our nuclear power programme. There are several aspects of the second stage that are yet to be fully unraveled. IGCAR is sharply focused on this mission, which has many dimensions and disciplines. So you need to train young scientists and engineers who are capable of taking this growing programme forward. We already have a unique laboratory complex that has given us world class capabilities. Many more would surely need to be added in years to come. Dr. Bhabha used to say, if you want to develop science "find a scientist and build a laboratory around the scientist not the other way round". So I feel, well focused training programme at IGCAR was important, is important and will continue to be important.

Sir, you have made many achievements in life, which one of them has been most challenging, most satisfying and most memorable?

I remember, when the nuclear tests were done, everybody said I felt like this and I felt like that. When I asked myself what I felt, the answer was I actually felt nothing more than having completed a planned task well. The only day when I was tensed up is when I did my first experiment with a newly built heat transfer facility that was unconventional and there was significant uncertainty about it in my mind. Let me narrate a related aspect of this story. At that time, there was a vibrant Indo-Canadian collaboration around development of PHWR technology. A large number of people were being deputed to Canada under this programme. Being a topper in training school, I was offered one such deputation within a short time. I however insisted that I will go abroad only to a University. Such opportunities were indeed available to early training school batches but the practice had been discontinued. Those days, unfortunately the mind set was that only people in basic sciences would do open ended research, whereas engineers would only build plants and do development and testing for equipment, processes and plants. In absence of an opportunity to go to a University, I decided to explore the possibility to register for a Ph.D. in engineering research while working in BARC. Neither BARC nor Mumbai University would facilitate such a thing at that time. IIT Bombay also did not have any scheme for external registration. It was under such circumstances that some of us felt that if we quickly create a large enough research facility that is not easily possible at an academic institution like IIT, the case for external registration could become stronger. So I along with Shri Ramamurthy decided to take up this challenge and built a boiling heat transfer facility in 6 months. It was not part of any plan project but was created purely for research. There was no budget and we had to design everything with the material available around. There was an old pump which was not working for the past several years. They told me that if I make this pump work, it will be mine. I made that pump work and that was mine, like that we assembled everything. If you construct several elements in series parallel combination in a network, where the capacities are very small and currents are large, it is an invitation for instability. The situation becomes worse when there is a relatively large transient energy

management as would be the case with experiments on critical heat flux. We therefore had to build in a good control system to ensure stable operation. I could not sleep the night before the facility was commissioned primarily on account of uncertainties that existed in my mind. When everything went well, I was naturally very happy. I have seen many and much bigger successes later, but at that very young age it was a blind spot lighting up - a eureka moment.

During which period of your career did you conceptualize AHWR? Is there scope for using metal alloy of thorium as possible fuel in AHWR and what are its implications with respect to reactivity feedbacks as we have in fast reactor materials?

Working in BARC, my focus has been on thermal reactors both based on uranium as well as thorium. I also had the good fortune of being associated with IGCAR though not directly, but initially as a member of PFBR working group to decide the configuration of PFBR and such other capacities later on. So I would say I had a reasonably deep understanding of all the three stages. Many in IGCAR in those days perceived talking for thorium as talking against Fast Reactors. I was very much convinced that the sequential pursuit of the three-stage programme as conceived by Dr. Bhabha, was the way we should go. I was also convinced that these were the long term technology development paths needing sustained efforts and so nothing in terms of research and technology development relevant to the three stages should be ignored. The issues on what comes first and what should be next is relevant primarily in the context of large scale deployment on which we have had a very clear policy.

BARC is a comprehensive research centre, much larger, broader, diverse and will remain strong in development of thermal reactors. It was quite natural that we did 235 MW PHWR systems and then the 500 MW system. It so happened that we had also finished DHRUVA in 1985. The question was what next? I felt, time had come to focus activities in BARC on thorium and take the prevailing experience in BARC on thorium to next higher level.

The choice of the reactor and fuel cycle configuration for the third stage would need to take several factors into consideration. Some of them would unfold during large scale irradiation of thorium in the later part of second stage. While molten salt systems may turn out to be a preferred choice for third stage programme based on a more fundamental logic, the final decision would need to be taken on the basis of well proven robust technology. In any case there was a need to develop program that would enable enhancing the experience with thorium derived fissile materials from kilogram scale to ton scale.

The other thing under discussion at that time was the need to improve safety of reactor systems in the context of Chernobyl accident. People were talking about the WASH 1400 report that dealt with the probability of severe accident in a reactor and the importance of a comprehensive PSA study. Even if the projected probability of a severe reactor accident was low at 10^{-4} , 10^{-5} or even 10^{-6} per year, with increase in number of reactors to hundreds or larger, a need was felt to evolve a design that not only would have much lower probability for a severe accident but even



Dr. Anil Kakodkar joined the Bhabha Atomic Research Centre in 1964, following the one year post graduate training with top rank in Nuclear Science and Technology in the then Atomic Energy Establishment. Dr. Anil Kakodkar obtained his B.E. in Mechanical Engineering from the Bombay University in 1963 and M.Sc. in the Experimental Stress Analysis from the Nottingham University in 1969. Currently he is INAE Satish Dhawan Chair of Engineering Eminence at BARC. He held various positions such as Director of BARC (1996), Chairman, Atomic Energy Commission and Secretary to the Government of India, Department of Atomic Energy (2000-2009), and DAE Homi Bhabha Chair Professor at BARC. Dr. Anil Kakodkar devotes his time primarily on issues related to energy, education and societal development. Utilisation of our vast Thorium resources for energy production has received special attention under Dr. Anil Kakodkar's leadership and a number of new technology areas such as accelerator driven systems, high temperature reactors, materials and recycle technology etc. have been nucleated. He has brought out more than 250 scientific papers and reports on various aspects of his work. He is a recipient of several national and international awards, notable among them are Hari Om Ashram Prerit Vikram Sarabhai Award in 1988, MRSI-ICSC Superconductivity & Materials Science Annual Prize in 1997, Padma Shri in the year 1998, Padma Bhushan in 1999, Padma Vibhushan & INS Homi Bhabha Life Time Achievement Award in 2009, "Maharashtra Bhushan" by Govt. of Maharashtra, 'Gomant Vibhushan' by the State of Goa, "Madhya Pradesh Gaurav" by Govt. of Madhya Pradesh and Rockwell Medal for Excellence in Technology in 1997. He is a fellow of various professional bodies such as Indian National Academy of Engineering, Indian Academy of Sciences, The National Academy of Sciences, Maharashtra Academy of Sciences, Hon. Fellow, Indian Institute of Technology, Mumbai, Fellow, Institution of Engineers, Hon. Fellow, Institution of Electronics & Telecommunication Engineers.

under such a situation would not lead to any impact in public domain. This was important from yet another point of view. Every time you set up a reactor, it requires exclusion radius and involves land acquisition on a large scale. For a dense country like India requiring large augmentation in power generation capacity, it was important to make large exclusion unnecessary. So I said let us design a reactor that does not require any intervention or cause a serious impact in public domain. I also said; let us try to achieve this with the broader technology set that we know today. Within the technology set that we have already mastered, can we create a design configuration, which will not cause any impact on the public? AHWR was thus conceived with the twin objective of eliminating the need for exclusion radius and enhancing our experience with thorium. That is the logic with which AHWR was conceived and that logic still stands. It is a thorium reactor but not a breeder reactor. A net consumer of fissile material, but it will definitely allow you to test fuel cycle technology related to thorium on a large scale.

There has been a lot of discussion on what should be the configuration of an ideal thorium reactor. There are aspects like low neutron flux that would facilitate better conversion of protactinium to U^{233} without being transmuted to higher atomic number species, taking advantage of low energy density in engineering and nuclear design and such others. We did toy with the idea of using metallic thorium. However, there are issues with metallic thorium in aqueous systems. AHWR objective is to build a reactor that is super safe and that demonstrates a significant energy from thorium largely making use of known technologies. AHWR is thus not to be confused to be a reactor that would meet the objectives of the third stage but rather a way to hasten development of thorium technology as well as propagate a feel safe feeling with respect to nuclear reactor technology.

How is a reactor that we see in a nuclear submarine different from the reactor we see at Narora or Kakrapar? What is the basic difference between the two?

The basic difference is the technology. Submarine reactor is a highly compact PWR.

Among the different reactor types, diffusion length and slowing down length with light water is the smallest and that really makes a PWR core more compact. More importantly there are further advantages of running this reactor in the intermediate spectrum.

The compactness is pushed significantly further in a PWR plant for a submarine by making equipment very compact as well as integrating design to realize multiple functions in a single equipment. For example if you want to transfer "X" amount of heat, can we do it in one third volume? Can you package the tube bundles in such a manner that we pack a much larger heat transfer area in a smaller volume? Fabrication of components of a submarine reactor is therefore very complex. Same thing is true with respect to equipment layout as everything has to be fitted in the space that you have within the hull. That is another challenge. It is a military machine, hence should have the agility (high power to weight/volume ratio), acceleration (ability to quickly raise power) and quietness. A submarine reactor plant packs much more energy for its volume. It is smaller than a nuclear power reactor but technologically very complex and more advanced.

In the morning you were talking about the research parks, how feasible it is to have the research parks associated with IGCAR or BARC?

I think it is quite feasible. While there are some aspects of technology development that necessarily have to be done in house, such as those dealing with radioactive and nuclear materials, there are others such as master slave manipulators, robotic devices, radiation shielding windows, detectors of different variety, non destructive examination, advanced materials, sophisticated computational codes and many others that also need to be developed through comprehensive R&D. While we need such technology products for our programme, there could also be a much larger market outside for such products. It thus makes sense to combine the capabilities of our laboratories as well as those of industry in a set up like a research park for such developments.

We now have HBNI where we have several research students, some who are regular employees inducted through the Training School and others who have taken admission in HBNI and are pursuing their Ph.D. If they can pursue research along with an industry in a concurrent development mode and work on problems which can ultimately lead to the industry commercializing a particular technology product, that is a critical need for DAE and also has a larger market outside, you fulfill the core objective of HBNI namely pursuing research on the interface of basic science and new technology as well as advance technological capability in Indian industry. Research Park operating in conjunction with HBNI would thus form an excellent ecosystem for research driven innovation furthering the core HBNI objectives. More importantly, through such a process, you create a career opportunity for HBNI graduates to be high-tech entrepreneurs or intrapreneurs and lead the way for a high-tech industry to support our growing programme. Today also such research may be pursued, but in absence of organized placement strategies, the scholar may end up in a job that has nothing to do with the particular product that might emerge based on his/her work. Further, in absence of a sustained strategy for translation of technology, expecting an industry to take up commercialization based on documentation contained in one Ph.D. thesis may be unrealistic. A research park could create a right ambiance both in terms career options for HBNI graduates as well as translation of technology to its logical destination.

Research Park at IIT Madras has been a very successful exercise. I see no reason why, whatever is happening at IIT-madras, should not happen at DAE laboratories like IGCAR

Sir, you spoke about Science Innovation Activity Centers at District level and introduced concept of "cillage", where research has direct interaction with the society. What initiative needs to be taken to implement it across India in a sizeable part? Is that individuals or groups of individuals have to take initiatives at different level or is that Government will take initiatives?

I think there has to be some facilitating environment to begin with and if Government does that, so much better. I would like to explain the idea of "cillage" (knowledge city in a village) in some detail. Cillage is a knowledge domain with state of art capabilities that is linked to development in the neighbourhood that is technology enabled. The objective is to create a development environment that should become self-sustained over a period of time. For example if you invest a couple of crores in creating such a development environment over a period of say three years, the money will be used to create some infrastructure and some facilities. At the end of three years this activity should be able to generate sufficient resources to sustain the development programme that has been initiated and generate a little bit of surplus. Financing knowledge and education part cillage has to be organized separately as a part of higher education development in the area. However just as the technology that enables higher livelihood and development remains at state of art level because of its linkage with the knowledge domain, linkage with development environment also brings in significant enrichment to education and research in the knowledge domain.

If we don't educate ourselves well, we keep on asking money from our parents, which is not a good way of development. If we educate ourselves well, we become independent and could in turn support our parents. Same is true with the society. You can take some money from the public to start with and start development activities in the neighbourhood. The neighborhood developments should over a period of time return back the money and of course continue to support the society. The key to this is the linkage between knowledge and development. That is the concept of cillage. My job at this moment is to try this out as an experiment. This is an experiment involving human beings. There are a large number of individuals involved and each of them has different ways of looking at things. I think it is an important thing to recognize and so we should go through such an exercise. I travel in these areas and the excitement I see is huge. If government takes these initiatives, it is well and good, my idea is only to create a demonstration of a model framework and show that it works. I am not alone, there is a large number of not just individuals, but institutions involved in this.

Science, Innovation Activity Centres are a different kind of intervention. The idea is to create sufficient number of science centres where school students can understand scientific principles through hands on working with dynamic models and address their curiosity through experiments that are custom designed and made by students themselves. To begin with the plan is to set up such SIACs in each district so that students from different schools in the area can benefit in time sharing mode. Such centres should significantly contribute to the spirit of innovation among young children.

How was your experience in the nuclear deal?

This was post 98, when we had carried out our weapons test and announced that we are a nuclear weapon State. Post 1974, the global nuclear architecture had undergone a major change primarily targeting India. We had lived through the embargo regime that was tightened around us. Our programme had moved forward undeterred by the embargo regime. It was only to be expected that post 98, the embargo would be even tighter. At the same time I could sense signals coming informally from a few important people abroad complimenting India for the newly demonstrated strategic capability acquired on our own. We had remained fully compliant with all our international agreements and behaved in a very responsible manner all along. So while the international community ostensibly had turned very hostile, there was also a feeling that there is nothing illegal about what we have done. This was also the time when the global community had started recognizing India's rising stature on account of growing economy and now the de-facto nuclear weapon status. There was also growing awareness about India emerging as a fast growing energy market, volatility in energy prices and the global climate change concerns on account of excessive use of fossil energy. In terms of geopolitics again India was becoming an important factor in the context of growing Chinese dominance.

Now the question was how we move forward following the post 98 events. For anything you must first identify what the problem is and what could be the solution. For me the definition of the problem was to get the embargo around us dismantled without compromising our strategic autonomy as well as our ability to move forward on our indigenous self reliant three stage programme. It was clear that NPT had come to stay. The question was how to make it irrelevant as far as India is concerned; in a sense it should not come in the way of India achieving the due status in the world. I had also figured out that the world respects you if the world concludes that it cannot do otherwise in terms serving their own interests. Strength respects Strength. One part of the strategy that was pursued in this context was to march ahead in terms of making significant advances in futuristic advanced nuclear technologies to convey a strong message on our domestic technological capability that will grow further on its own steam not withstanding external restrictions. The launch of Prototype Fast Breeder Reactor construction was an important mile stone, in terms of telling the world that we are moving forward. We also made several other progresses related to strategically important technologies such as in nuclear submarine, enrichment, lasers, nuclear recycle, thorium, fusion energy and many others. All this, which any way was a part of our preplanned domestic programme, was aggressively pushed forward even as the crisis on availability of uranium was becoming bigger by the day. So, augmenting uranium production through development of new mines, reconfiguring power

reactor cores to enhance energy output from the available uranium, making use of depleted uranium and such other innovative measures were adopted to ensure that NPCIL does not go in red on account of reduced capacity factor of their operating power plants. Emphasis on power plant construction programme was also maintained on the basis of projected growth in domestic uranium production. The approach adopted was to demonstrate all round progress and at the same time recognize the space for inputs through external sources to speed up the nuclear power programme implementation.

In parallel a lot of political processes were going on post 98. After initial years of very tough discussions between India and the US, Next Steps in Strategic Partnership (NSSP) emerged. Simultaneously, there were ongoing dialogues with the French, the Russians and the UK. As a result of intense diplomatic processes, slowly things started easing up. There were a series of events one after the other. It was clear to me that others needed the co-operation as much as we needed it. It was like a poker game and you have to play your game right. It was driven by a sort of mutual interest between countries with each trying to maximize the advantage for themselves. A further complexity was on account of the fact that apart from bilateral dialog with key countries, there was also a question of dealing with multilateral fora like the IAEA and the NSG which also must turn supportive for success to be realized. United States was thus a very important country. Apart from dealing with other countries, I felt there was a considerable desperateness in some quarters within the country who wanted the deal with US at any cost not realizing our strengths and also the serious implications of a bad compromise. Those were high tension days in true sense of the word. There was threat to fast breeder and reprocessing programme and in turn to the three stage programme itself on one side and to viable performance of NPCIL reactors on the other. In the end a satisfactory understanding could be reached. We had no problem putting whatever comes from outside under IAEA safeguards as we had been doing right since Tarapur 1&2 reactors. We had also been able to build multilayered safeguards to protect us against any supply disruptions should they happen in the changed political circumstances. The decision to put a facility under IAEA safeguards would be entirely ours and would be premised on assured unrestricted international commerce for the supplies needed. My only unfulfilled desire is to see the resultant rapid growth of nuclear energy in India. That momentum is yet to pick up.

Do you feel the role of basic sciences in BARC, IGCAR has changed?

It has changed a lot according to me. In my view, research in basic sciences is pursued to push the knowledge frontiers forward whereas research in applied sciences is aimed at supporting development and generation of wealth. Both are important for welfare of the society. More ever capability to quickly evolve a technology out of latest in basic research ahead of others gives you a great competitive advantage. While one can clearly notice this feature in technologically advanced countries, in India we are by and large rather weak in our ability for such translational research.

In BARC, IGCAR and such other centers of DAE I think we have a unique advantage in terms of connecting research in basic science with technology development. We have done rather well in leveraging our technological capability for building instruments and research facilities both for basic science research as well as for applied research. We should now focus on leveraging new discoveries in basic sciences for developing new technology products, particularly those that we would need in our emerging programme. This is important since our programme in many respects is likely to move ahead on new path ways that others might take up much later. We need to build a strong culture of translation research for this to happen. While one may decide to work in an area of one's choice, where ever there is an opportunity to translate research towards a new technology product, one must do that either directly or through an interested collaborator. Creation of HBNI is based on the premise of such capacity building. Hopefully, over a period of time, we will have a large enough number of researchers who can competently work on the interface domain between basic research and technology products. Basic research is thus important not just for advancing the frontiers of knowledge, but also to evolve new technologies ahead of others.

IGCAR is active in development of fast reactor and related technologies. Not many countries are in this field. Moving forward, we may have to pursue areas like metallic fuel, pyro-chemical reprocessing, thorium in fast reactors etc. that are completely new. This is where knowledge base arising out of basic research would be very important. Countries like US, Russia, France and Israel are strong because they keep bringing out first of kind technologies faster than others. Thanks to Nokia's mobile technology, Finland's economy saw a major upward swing. We need to build such a capability in India. That is the additional dimension that we should bring in basic science research.

Sir, Can you share your responsibilities in the safety review committee of the Railways? Is there any possibility of operating high speed trains between important cities like Mumbai to Pune, Bengaluru to Chennai. Can you share your experience with us?

My mandate in that committee was essentially related to safety. There was another committee working in parallel, looking at technology and commercial issues. Both the committees submitted the report to the Government almost at the same time. Our report thus is essentially on technology, policy and administrative aspects related to safety on railways. I feel the railway employees have good competence, but they are structured very badly, for example there is no research organization worth the name in the railways. There is an RDSO (Research Designs and Standards Organization), where the recruitment is only at assistant level and there is no recruitment at the officer level. The Director or

General Manager is recruited through Indian Railway Service of Engineers who is posted at RDSO for a period of 3-4 years. It is difficult to run a research laboratory with such an organizational structure. Even so we must recognize that they have developed several technologies.

Ensuring safety of public requires new configurations and technologies particularly as the speed of trains as well as number of trains are going up. Also we need considerable augmentation in in-service-inspection of all technological assets. Then there is a question of effective safety regulation. We have made several recommendations such as elimination of level crossings, design improvements to prevent jumping of coaches consequent to a collision, improvement of rails, improvement in signaling system, thrust on research, restructuring of regulatory framework and several others. We had discussions with all stakeholders and made sure that the ownership of this report is with them. So, in spite of ministers changing, that report is still talked about. The current minister has told me that they are implementing the report.

You have headed committees comprising of scientists, administrators and social scientists. How have you been able to bring them to a common conclusion when their lines of thoughts are in different direction and starting points are vastly different?

That is simple. Shared vision, coherent thinking is the key. First be sure that everybody on the table is sharing the same vision and same objective. Then there may be different approaches and different ways of looking at it. Test them out in terms of the best path in the context of the shared vision and bring in the coherence. I have never failed on this. Only thing is that you must approach issues with an open mind, you cannot have closed mind yourself. When you have closed mind and say let us have shared vision that does not work.

The way our Department is shaped, the way our Department could take up the challenges, do you believe that others have replicated, if not why?

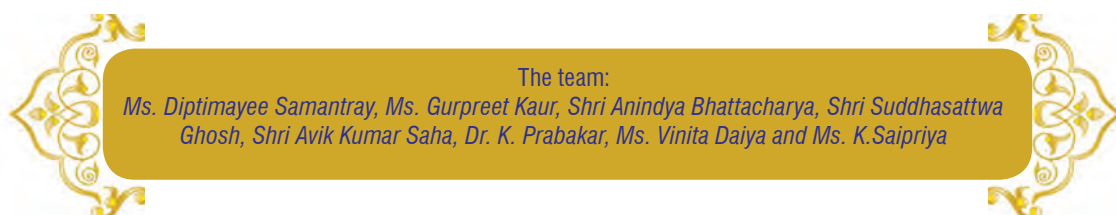
There are several examples of adoption of good features of DAE in other spheres. For example, the Department of Space, the way it works is very close to DAE; in fact it evolved out of DAE. Not that they have just copied us, they have their own innovations, but they are very similar. There are many others who just want to copy what we have done. It is often not understood that just copying the system doesn't mean that you will get success. You must understand the underlying philosophy with which the system works. Most times, some high level committee would discuss, say DAE system does things well and ask for replicating the DAE system in their respective organizations. I used to get letters asking about the career progression policy for example. To all such people who did not seem to have bothered about understanding the underlying philosophy, I have never replied. Just copying a piece of paper and implementing it mechanically is unlikely to work.

Today IIT's have a floating advertisement; they don't specify a specific number of vacancies that they would like to fill. They have a clear idea of the qualifications, caliber, experience and performance expected from a faculty. They have a peer based selection process that can ascertain all these parameters as and when a new faculty wants to join. Thus rather than recruiting to fill in the vacancies, one is in the process of searching and inviting talent. Our training school selection or for that matter selection through the prospective candidate route has been having this underlying principle right from the day one.

I want to use this occasion to also highlight the performance assessment system that has been in vogue in DAE right since its inception. In the annual performance assessment form, you write an account of what you did during the year. Integral with that on the other side of the same paper is the space for overall comments and counter signature of senior people in your hierarchy. In between you have separate loose sheets where detailed assessment by all people with whom you have worked is recorded. Dr. Bhabha's original order on this subject had visualized that a person can be working with several groups not necessarily within the chain of individual's hierarchy and there must be an assessment of your performance in all those groups. So these are all individual sheets and there should be as many sheets as the number of groups you are working in. Some of the people who have assessed might be very senior as compared to your section head or the division head who do the countersigning taking all inputs from various assessors into account. I have always viewed this system a key to sustaining an environment of innovation where scientists can freely interact in an organized way and contribute with their ideas and capabilities without hierarchical barriers. I believe this along with our peer driven performance based merit promotion system to be at the heart of our success.

I have a sense that the system has got somewhat compromised over years and the grip of hierarchy at times comes in way of cross fertilization of ideas. We need to be on the vigil, always, to protect the integrity of process, that has been thought through extremely well by Dr. Bhabha and correct it back wherever we might have compromised the process.

Thank You Sir for spending your valuable time with us.



Establishing Atmospheric Plasma Spray and High Velocity Oxy-Fuel Spray Facilities for the Development of Metallic and Ceramic Coatings for FBR and Fuel Cycle Applications

Pyrochemical reprocessing route will be adopted for the separation of uranium and plutonium from the spent metallic fuels of future sodium cooled fast breeder reactors. Stainless steels (SS), Cr-Mo steels, Ni-based alloys and High density graphite (HDG) are considered as structural materials for the various steps involved in pyrochemical reprocessing. Unit operations such as salt purification, electrorefining, cathode processing and injection casting in the pyrochemical reprocessing involve highly aggressive molten LiCl-KCl salt and molten uranium at temperatures in the range 500-1500°C. Hence, the corrosion behavior of these structural materials in the molten salt and molten uranium needs to be evaluated. Earlier studies on the compatibility of the structural materials in these corrosive environments revealed the need of proper ceramic coatings on these structural materials. The ceramic coatings should be inert, possess non-wetting characteristics, adequate bond strength with the substrate, and should withstand thermal cycles in the long term service. Hence, ceramic coatings with the required features need to be developed. Thermal spray process is a versatile technique in which finely divided metallic or non-metallic powders are deposited in molten or semi-molten state on the substrate to form an adherent coating.

APS and HVOF Facilities

In Corrosion Science and Technology Group (CSTG) various plasma sprayed ceramic coatings were developed on different structural materials for pyrochemical reprocessing applications in collaboration with industries and the corrosion behavior of the coatings was evaluated. Recently, an Atmospheric Plasma Spray (APS) and High Velocity Oxy-Fuel (HVOF) Spray facilities (Figure 1) have been established for depositing various ceramic and metallic coatings for applications in pyrochemical reprocessing as well as fast breeder reactors. The major components in these facilities include

1. SG-100 plasma spray torch for external coatings with the maximum power capacity of 80 kW.
2. SG-100 plasma extension torch for internal coatings with maximum power capacity of 40 kW and spray angle as 45 degree and capable of coating tubes of length up to 600 mm and inner diameter of 75 mm and above.
3. Gas fueled HVOF (Diamond Jet) torch for developing strongly adherent alloy and cermet coatings.

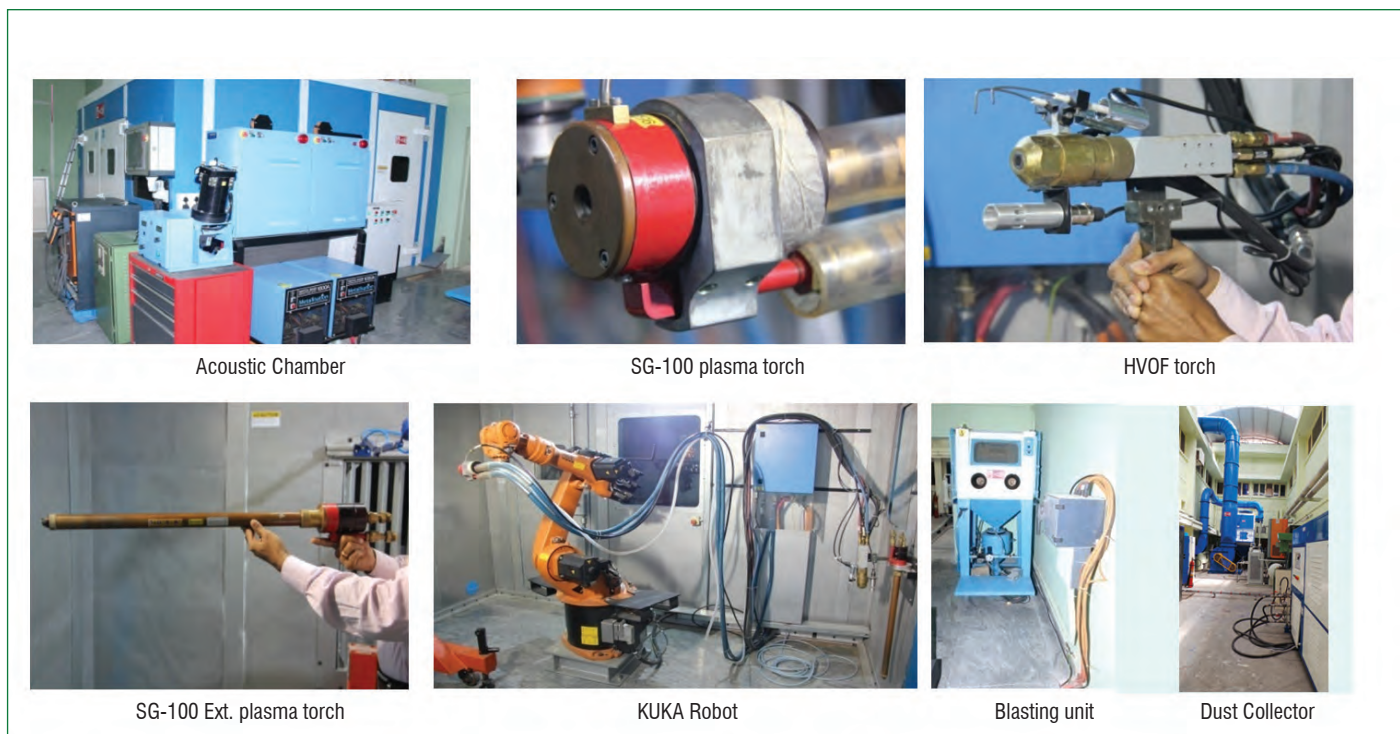


Figure 1. APS and HVOF spray facilities at CSTG, MDL building

4. Industrial robot with payload capacity of 16 kg, for mounting and handling the spray torches for coating job.
5. Pressure blasting unit for grit blasting the substrate using alumina grit before depositing the coating.
6. Accessories such as inverter power supply, mass flow controlled powder feeder, acoustic chamber with dust collector, 10 TR industrial chiller, air compressor and various types of gas bottles.

The APS and HVOF systems were successfully installed as part of XII plan project. The performance of these systems was evaluated by depositing NiCrAlY bond coat and Yttria Stabilized Zirconia (YSZ) top coat on all sides of a cylindrical Inconel 600 crucible (Figure 2a) of dimensions 300 mm OD, 600 mm length and 6 mm wall thickness using SG-100 plasma torches and also by depositing NiCrAlY bond coat by HVOF torch and YSZ top coat by SG-100 plasma torch on the top surface of Inconel 600 rods of 24 mm diameter for performing adhesion test.

Coatings on metallic substrates and graphite for molten salt applications

As metallic and graphite structural materials proposed for various components for pyrochemical reprocessing will react with molten salt at high temperatures and undergo significant corrosion and degradation, Yttria Stabilized Zirconia (YSZ) coatings were deposited on structural materials such as 9Cr-1Mo steel, 316L SS and HDG graphite and their compatibility with LiCl-KCl molten salt was evaluated up to 2,000 hours at 600°C. For the development of bond and top coats, the parameters for coating were optimized for plasma spraying. The percentage weight loss of the uncoated

316L SS sample exposed to molten salt at 600°C for 250 hours was 2.83, while the percentage weight loss of YSZ coated 316L SS exposed for 1000 hours was only 0.08, indicating that the corrosion attack on YSZ coated 316L SS was insignificant. The cross-section optical micrograph of unexposed and exposed YSZ coated 316L SS were more or less similar and did not reveal any penetration of the salt across the coating. The percentage weight loss of molten salt exposed YSZ coated structural materials at 600°C for various durations is shown in Figure 3. Negligible weight loss observed for the YSZ coated HD graphite sample after exposure to molten salt for 2,000 hours is an evidence that YSZ coating performed well in molten LiCl-KCl salt. There was no change in the surface morphology of YSZ coating after 2,000 hours immersion test. The YSZ coated 9Cr-1Mo steel samples tested up to 2,000 hours showed a minor increase in weight and the coating exhibited significant cracks and buckling. Though spallation of YSZ coating on 304L SS led to an increased weight loss, the coated specimens exhibited better corrosion resistance in molten LiCl-KCl salt than that of uncoated specimens.

Ceramic coatings for uranium melting applications

High density graphite is proposed as the candidate material for the cathode processor and injection casting crucibles in the pyrochemical reprocessing of spent metallic fuels. Cathode processing is one of the key steps in pyrochemical reprocessing in which the deposited uranium on the cathode is consolidated by melting in graphite crucible and casting in the form of rods. Though graphite is a high melting material exhibiting excellent corrosion and thermal shock resistance, it undergoes severe oxidation in atmospheric air at temperatures above 500°C. As melting of

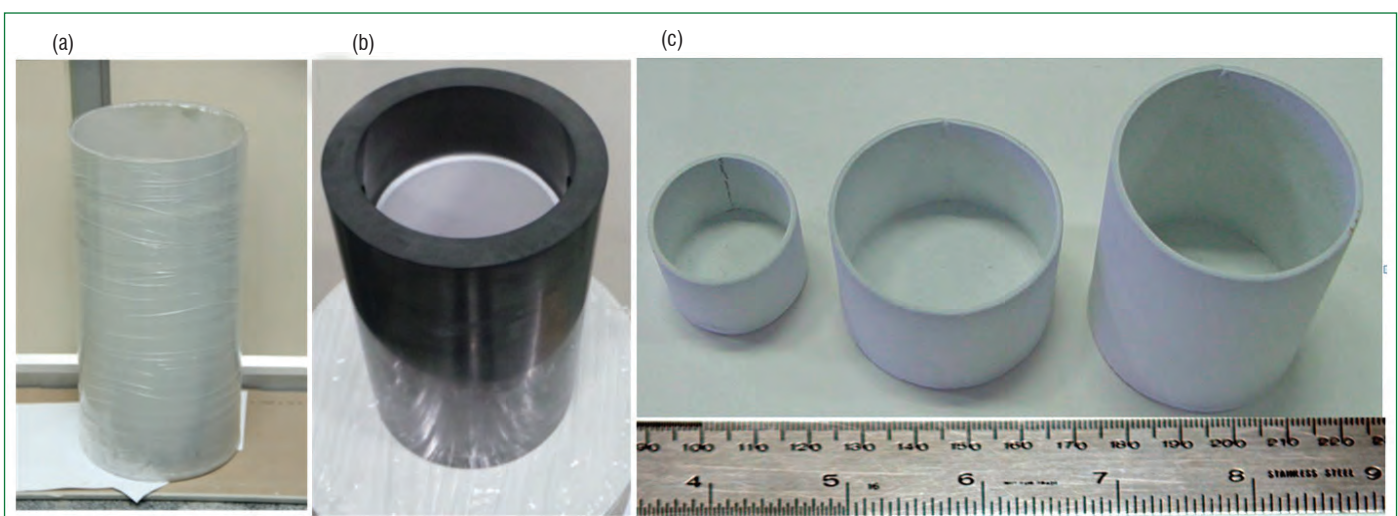


Figure 2: (a) YSZ coated Inconel 600 crucible (300 mm OD and 600 mm length)
(b) Yttria coated HDG crucible and (c) Alumina coating on SS430 crucibles

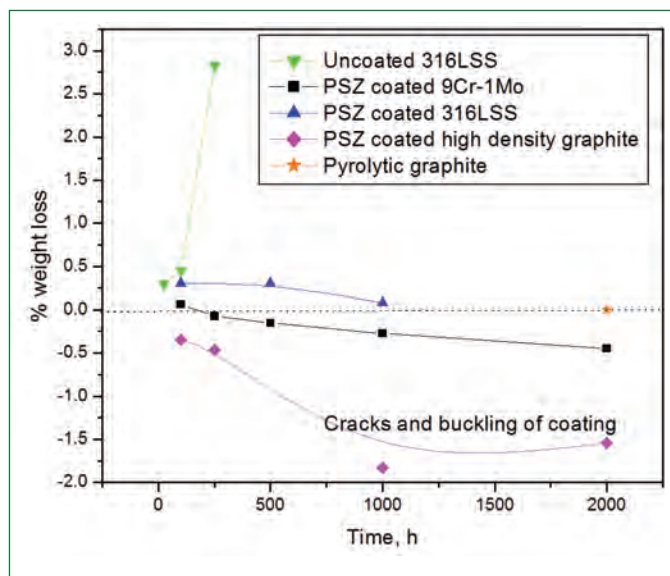


Figure 3: Weight loss (%) of YSZ coated candidate materials exposed to molten salt at 600°C

uranium and its alloys (U-Pu, U-Pu-Zr) is carried out at temperatures above 1400°C, it is essential to protect the graphite crucible from oxidation and to prevent undesirable reactions between reactive liquid uranium and graphite. This could be achieved by providing a protective and non-reacting ceramic coating. Coatings of YSZ with NiCrAlY bond coat and alumina-40% titania (A40T) with Cr₃C₂-NiCr bond coat were deposited on HDG and their performance was evaluated in uranium melting experiments. YSZ coating was intact after the uranium melting, but A40T coating peeled off completely along with bond coat. It was observed that A40T coating exhibited poor adhesion on HDG, but the A40T coating deposited without bond coat showed better bond strength. YSZ coating maintained its integrity without any phase change in the coating after uranium melting at 1350°C and no reaction with uranium was observed, as inferred from XRD and Raman studies. Among the commercially available ceramics, yttria (melting point: 2410°C) offers excellent protection to graphite as it does not react with uranium up to 2000°C. It is imperative to consider not only the type of ceramic coating developed over HDG, which ensures the protection of HDG from molten uranium alloys, but also the interaction of the coating with carbon at higher temperatures.

Literature revealed that yttria coating reacts with carbon at about 1500°C and forms yttrium carbide and releases CO and CO₂, which contaminate the molten metal and also destabilize the coating leading to failure of the coating. Hence, a suitable interlayer coating between HDG and top yttria coating is desirable for uranium alloy melting applications. Thus, yttria coating with NiCrAlY bond coat were developed on HDG coupons (Figure 4) and their thermal

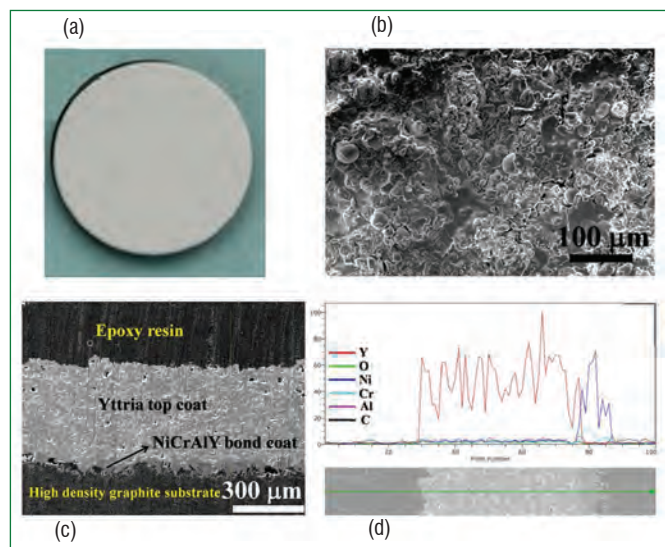


Figure 4: (a) Photograph of yttria coated HDG specimen; (b) SEM image of yttria coating on HDG; (c) SEM cross section image and (d) EDS line profile of the yttria coating

cycling life were evaluated at 1000 and 1100°C. The compatibility of the coating with molten uranium was also investigated. Visual examination of yttria coated high density graphite samples revealed spallation of the coating during 36th thermal cycle at 1000°C and 20th cycle at 1100°C. Uranium melting experiments confirmed the compatibility of coating with molten uranium for three melting cycles without coating spallation. Yttria coating without any bond coat was also developed on HDG crucibles for metal melting applications due to the limitation in the use of NiCrAlY bond coat, which melts at about 1300°C. Plasma sprayed yttria coating without bond coat performed well for more than 40 copper melting cycles at 1150°C and for five copper melting cycles at 1400°C. Yttria coated HDG without bond coat could withstand 245 thermal cycles at 1000°C and ten uranium melting cycles.

Based on the experience gained in the development of yttria coatings on HDG discs and crucibles of smaller dimensions, 250-300 μm thick yttria coatings with NiCrAlY and without any bond coat were deposited on the inner side of engineering scale HDG crucibles (Figure 2b) of dimensions 145 mm OD, 120 mm ID and 220 mm height for Demonstration Facility for Metallic Fuel Fabrication (DFMF). Simulated copper melting and uranium melting experiments were carried out in these coated crucibles in an induction heating facility. The yttria coating showed good adhesion behaviour and the uranium metal ingot could be easily removed after the melting runs. Copper and uranium melting experiments at high temperatures confirmed the integrity of yttria coating on HDG crucibles.

For further improvement of the adhesion of yttria coating on HDG

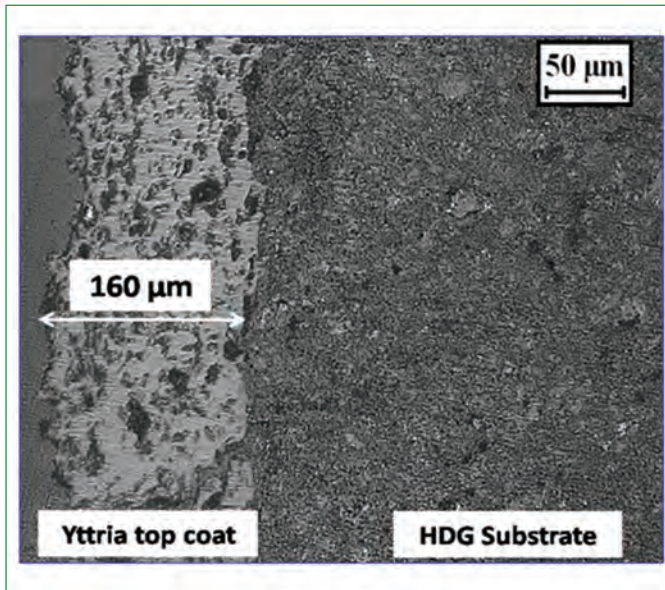


Figure 5: Optical micrograph showing the coating cross sectional thickness of yttria deposited over SiC interlaid HDG.

for uranium melting, a stable interlayer coating between HDG and yttria top coat was developed by pack cementation route. Literature survey and thermodynamic calculations revealed that carbides of Si, Zr, Nb and Ta are very stable and compatible with graphite. Hence, by providing an intermediate carbide layer as a reaction barrier between graphite and yttria, unwanted reduction reactions can be avoided, thereby improving the working temperature limit and durability of yttria coating on graphite crucible. A dense uniform SiC layer on HDG coupons was obtained with the powder pack consisting of SiO₂, SiC and carbon at the optimized time and temperature of pack cementation (Figure 5). After providing a SiC layer over HDG substrate, dense yttria coating was deposited as top coat by APS process with optimized parameters. The performance and durability of the multilayer coatings were evaluated by carrying out thermal cycling studies at 1400°C and above under inert argon gas environment. The interlayer of SiC facilitated to extend the thermal cycling life of the coating significantly. The onset of micro-cracking in the coating occurred after 21, 12 and 2 thermal cycles at 1400, 1450 and 1500°C respectively. To extend the thermal cycling life of carbide interlaid yttria coatings on HDG, attempts are being made to develop ZrC interlayer between yttria top coat and HDG substrate by pack cementation process.

Development of ceramic coatings for reactor applications

High purity alumina, exhibiting high electrical resistivity has been proposed for coating on Inconel 600 rings for application in high temperature fission chamber neutron detectors in fast breeder reactors, at the operating temperature of 650°C. For improving

the thermal cycling resistance and adhesion strength of alumina coatings, selection of suitable bond coat and coating technique, with appropriate spray parameters is essential. The bond coat material, Ni-50%Cr was deposited over Inconel 600 rings by HVOF spray process to achieve dense and adherent coating while the top alumina coat was deposited using plasma spray process. The SEM examination indicated splat type of morphology and the coating was dense with minimum porosity and no micro cracks. Thermal cycling studies at 650°C on coated samples and rings showed significant improvement in thermal cycle life and no weight loss, delamination/detachment of the coating was observed after 100 cycles (Figure 6). Plasma sprayed alumina coating showed adhesion strength of 38 MPa in the as-coated condition and the adhesion strength after thermal cycling for 25, 50 and 100 cycles was 35, 33 and 32 MPa respectively, indicating that the decrease in bond strength after thermal cycling was only marginal. The coating exhibited a stable insulation resistance (600V DC) of $\sim 10^{11} \Omega$ at room temperature and $\sim 10^8 \Omega$ at 650°C. The insulation resistance at 650°C satisfied the acceptance criterion. However, the insulation resistance at room temperature was found to be lower than the specified value.

Plasma sprayed coatings usually contain about 10% porosity. As moisture present in the porous coating affects the insulation resistance of the alumina coating, aluminium phosphate sealing has been proposed as an option to decrease the porosity present in the plasma sprayed alumina coating, thereby improving its electrical insulation resistance. Inconel 600 substrates were grit blasted and coated with NiCrAlY bond coat and alumina top coat of thicknesses 50 and 250 μm , respectively. Sealant solutions were applied over plasma sprayed alumina coated Inconel 600 samples and heat treated either in air or vacuum for 2 hours at 200°C, followed by soaking for 2 hours at 400°C and 2 hours at 600°C. Electrical insulation resistance of the alumina coated samples improved by an order of magnitude ($\sim 10^{12} \Omega$) at room temperature upon sealing when compared to unsealed coating. Sealing of thermal spray coatings using inorganic aluminium phosphate also facilitates to improve the performance of coating in molten salt and in reactive molten metals by preventing the impregnation and wetting of the corrosive molten medium. Further improvement in the thermal cycling life of top alumina coating can be achieved by nanostructured coatings. To improve electrical insulation resistance, optimising the coating parameters to reduce the porosity and identifying the proper composition of sealant materials and baking conditions are under way.

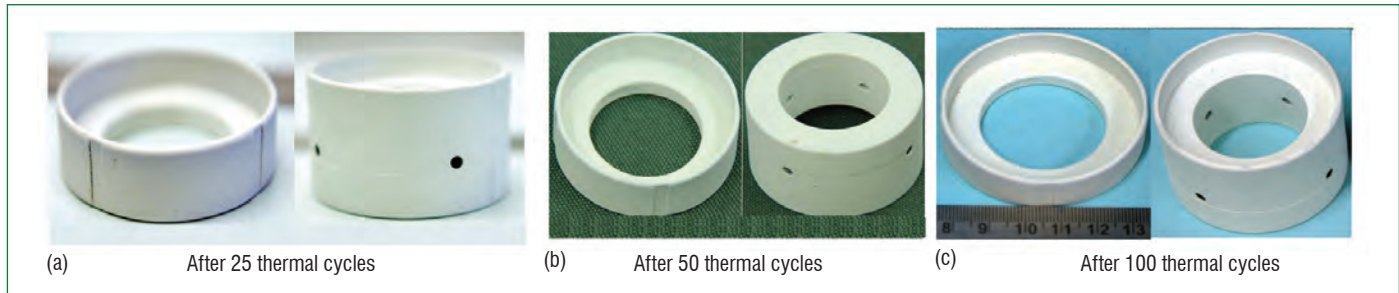


Figure 6: Alumina coated Inconel 600 collars/rings

Multi layer coating on core catcher plate

In the event of a Core Disruptive Accident (CDA) resulting from Unprotected Transient Overpower Accident (UTOPA) or Unprotected Loss of Flow Accident (ULOFA) in sodium cooled fast reactors, the fuel assemblies may melt rapidly and slump down. Owing to high temperature of the melt ($> 3500^{\circ}\text{C}$), the grid plate may also melt and the corium (molten fuel) comes in contact with liquid sodium present in the cold pool below the core support structure. This leads to energetic/non energetic interaction between the molten fuel and sodium, generating fragmented fuel debris. The main function of core catcher includes collection of debris, dispersion of debris to avoid re-criticality and cooling of the core debris bed considering the decay heat. As high thermal load is anticipated from such whole core melt down, the core catcher plate of SS 316LN will not withstand and hence, thermal barrier coatings with low thermal conductivity and high melting point having the potential to protect the core catcher plate from molten corium have been proposed. For this purpose, suitable multi layer core catcher, comprising a ceramic layer (which can be single or multiple layers) with suitable bond coat over 316LN SS is being developed at CSTG. To evaluate the stability of ceramic oxides during long term exposure to reactor grade liquid sodium and the integrity of coating under simulated molten oxide/metal impingement, coating of 250 micron thick YSZ and alumina were deposited over 316LN SS substrates with 50 micron NiCrAlY bond coat. Coatings were deposited with SG100 plasma gun using optimized process parameters. One set of the coated samples (YSZ and Al_2O_3) were subjected to molten oxide/metal (Termite mixture of iron oxide and aluminium powder) drop study at Safety Engineering Division, IGCAR and post evaluation of the coating integrity is being pursued. Long term sodium exposure and post characterization of the coated specimens are in progress.

Adherence to international codes and standards

The parameters for the operation of plasma gun are optimized for

the deposition of various coatings and the following international standards are used for evaluation:

- Surface preparation by grit blasting as per ASM and NACE standard No.1/SSPC-SP5.
- Metallographic sample preparation for plasma spraying as per ASTM standard E1920-03.
- Evaluation of porosity in plasma sprayed coatings as per ASTM E 2109 practice.
- Measurement of tensile adhesion strength of thermal spray coatings as per ASTM C 633-01.

Other testing and characterization like thermal cycling, thermal shock resistance, hardness, corrosion testing and monitoring are as per ASM and other international body guidelines.

The APS and HVOF facilities are employed extensively in the development of various types of corrosion resistant ceramic and metallic/alloy coatings on the structural materials for pyrochemical reprocessing, fast breeder reactor and allied applications. Thick alumina coating ($200\ \mu\text{m}$) with NiCrAlY bond coat ($50\ \mu\text{m}$) was deposited using APS system on SS 430 crucibles (Figure 2c) of three different dimensions for evaluating their performance as the container material for liquid cadmium cathode in the electro-refiner in pyrochemical reprocessing. $100\ \mu\text{m}$ thick alumina coating was provided by plasma spraying on grit blasted Inconel 718 rods of diameter 12.5 mm. Ytria coating ($50\ \mu\text{m}$ thick) was deposited on the inner surface of two tantalum Knudsen cells and lids. Since the diameter of the cells were $< 12\ \text{mm}$, separate fixture was machined out from a 20 mm dia SS rod with the provision to accommodate the cell and lid.

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Stimuli-responsive Microgel Suspensions: Ordering, Dynamics and Rheology

Stimuli-responsive microgels are submicron sized polymeric gel particles which, in aqueous suspension, responds to external stimuli like temperature, pH and ionic strength. Poly (N-isopropylacrylamide) (PNIPAM) microgels are thermo-responsive, which at room temperature stays in a swollen state in the presence of water. At a temperature of 34 °C, PNIPAM microgels undergo sudden volume transition to collapsed state by expelling water and above microgel particles remain in deswollen state. The temperature at which deswelling occurs is known as volume phase transition temperature (VPTT). PNIPAM microgel particles can be made pH and ionic responsive by addition of appropriate functional groups. Dense suspensions of monodisperse PNIPAM microgel particles exhibit liquid-like, glass-like and crystalline ordering, similar to that of atomic systems. Length scales of PNIPAM microgel particles are of the order of 100nm to $\sim\mu\text{m}$ and dynamical time scales involving their motion ranges from μsec to ~ 1000 sec. Thus, static and dynamic light scattering are appropriate techniques to investigate the structural ordering and dynamics in microgel suspensions. The tunability of PNIPAM microgel particle size and hence interparticle interactions with temperature makes the phase behavior of dense suspensions rich and interesting. Ordered structures of PNIPAM microgels are found to have several potential technological applications such as sensors for temperature/pH/various chemicals. PNIPAM microgels are biocompatible and hence used in controlled drug delivery. Since PNIPAM microgels have large solvent holding capacity (contains only 2-3% of polymer and rest solvent, in swollen state), they find wide applications in solvent extraction and purification processes. Unlike suspensions of hard sphere or charged colloidal particles, PNIPAM microgel particles are soft and inhomogeneous in density (core-shell structured, inset Figure 1) with dense core and a shell of dangling polymer chains. The hairy shell of PNIPAM microgels is expected to strongly influence the structural ordering, dynamics and shear flow (rheological behavior) under dense conditions. In order to investigate the structural ordering, dynamics and shear flow in microgel suspensions under dense conditions, monodisperse PNIPAM microgel particles of various sizes have been synthesized. Temperature response for PNIPAM microgels of two representative sizes, measured using dynamic light scattering technique, is shown in Figure 1.

Pressure response of PNIPAM microgels

As mentioned above, PNIPAM microgel particles are known to be temperature responsive. However, their response to osmotic pressure under dense conditions is not established. In order to study the influence of the osmotic pressure exerted by surrounding microgel particles, dense PNIPAM microgel crystals with different

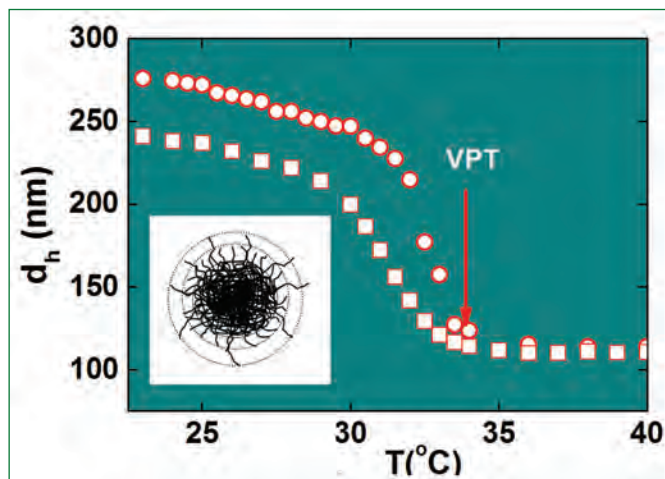


Figure 1: Variation of PNIPAM microgel diameter, d_h with temperature, T . Inset: Schematic of the core-shell structure of PNIPAM microgel particle.

volume fraction, ϕ have been prepared. Figure 2(a) shows the Bragg diffraction of PNIPAM microgel crystals recorded using UV-Vis spectrometer, at $T = 22$ °C. Upon increasing the volume fraction, hence osmotic pressure, Bragg peak is found to exhibit a blue shift. The near neighbour separation, d_{nn} determined from the Bragg peak as a function of volume fraction is shown in Figure 2(b). Beyond a certain osmotic pressure, d_{nn} is found to be smaller than the size of PNIPAM microgel particle under swollen state, d_h (i.e. $d_{nn} / d_h < 1$). In dense PNIPAM microgel crystals, the interparticle separation being lesser than microgel particle diameter in its swollen state provides direct evidence for deswelling of PNIPAM microgel particles under osmotic compression. The deswelling occurs due to osmotic pressure (\sim kPa) arising from surrounding microgel particles. Thus, our experiments reveal the pressure responsive nature of microgel particles.

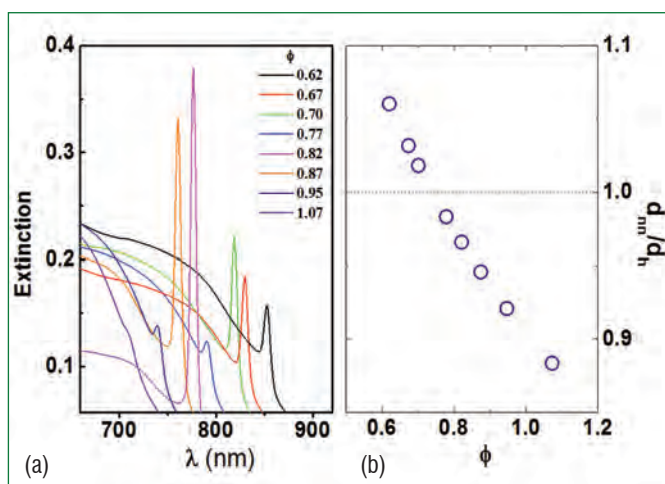


Figure 2: (a) UV-Visible spectra showing Bragg peaks and (b) d_{nn}/d_h for PNIPAM microgel crystals with various volume fractions, ϕ

Dynamics in dense microgel crystals undergoing melting

Melting of crystal into a liquid is a classic example of first order phase transition and is identified using well known Lindemann criterion and Hansen-Verlet criterion. Both these criteria are based on static properties and have been found to be applicable for colloidal systems. Though colloidal systems mimic atomic systems in structural ordering, they differ in dynamics. In atomic systems the dynamics is ballistic, whereas Brownian motion governs the dynamics in colloidal systems. The dynamics in colloidal liquids (i.e. liquid-like ordered suspensions) is characterized by short time self diffusion coefficient (D_S) and long time self diffusion coefficient (D_L). D_S is defined for short time scales over which particle traverses the distance smaller than its diameter and does not encounter any interaction from surrounding particles. On the other hand, D_L is defined for longer time scales over which particle traverses the distance larger than its diameter and encounters direct interactions from surrounding particles. Realizing this fact, a phenomenological dynamical criterion for colloidal liquids undergoing freezing into colloidal crystals has been suggested in literature. The dynamical criterion states that the ratio D_L/D_S , at the freezing/melting point, is a universal number (i.e.) $D_L/D_S \sim 0.1$. As the colloidal liquid freezes into a colloidal crystal, it is the long-time diffusion that decreases and slows down near freezing transition. Thus monitoring D_L helps in identifying the freezing/melting transition. In dynamical criterion D_S sets the scale for D_L , similar to the Lindemann criterion where lattice constant sets the

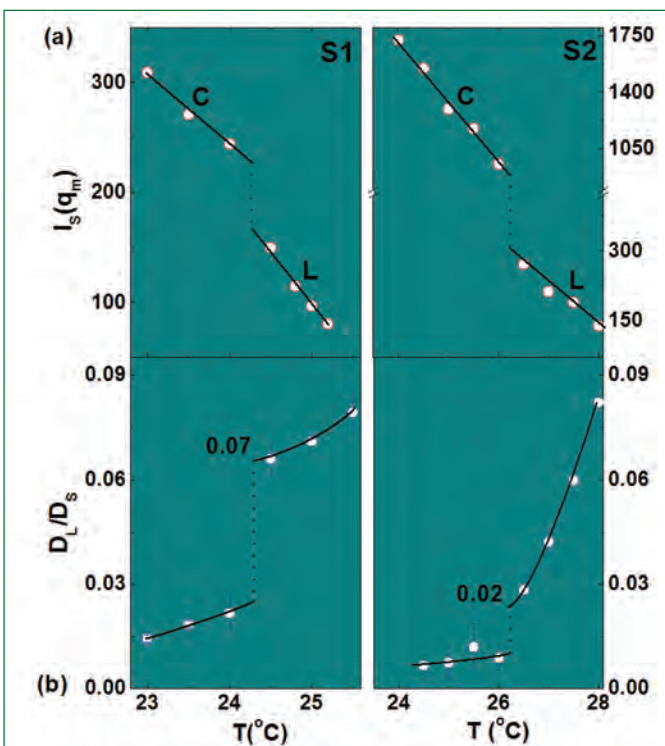


Figure 3 (a) Bragg peak intensity, $I_s(q_m)$ and (b) D_L/D_S , as a function of T for PNIPAM microgel crystals of sample S1 and S2. Dotted line: Melting transition of the crystals (C) into liquid-like order (L).

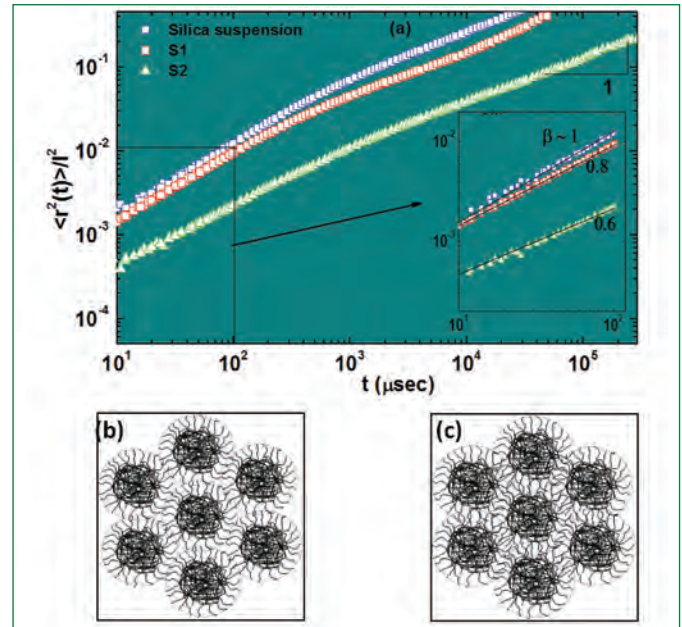


Figure 4 (a) Mean square displacement (MSD) of PNIPAM microgel samples S1, S2 and charged silica particles suspension close to their melting/freezing transition. Inset: Enlarged view of short time MSD. Schematics depicting entanglement of dangling polymer chains of neighboring PNIPAM microgels, in low ϕ sample S1 (b) and high ϕ sample S2 (c).

scale to root mean square displacement, and hence dynamical criterion is also referred as dynamical Lindemann criterion. The applicability of dynamical criterion has been verified experimentally and through simulations for freezing of colloidal suspensions of hard-sphere and charge stabilized particles. But its applicability to the suspensions of core-shell structured PNIPAM microgel crystals undergoing melting is unknown. Here, we have studied the dynamics across the melting of PNIPAM microgel crystals towards verifying the applicability of dynamical criterion to dense microgel suspensions.

PNIPAM microgel crystals having volume fraction (ϕ) at 23 °C, 0.49 and 0.79, named as S1 and S2 respectively, have been used for investigations. Bragg peaks from these crystals have been recorded using static light scattering (SLS) and dynamics have been measured using dynamic light scattering (DLS) technique. In order to identify the melting transition, Bragg peak intensity has been monitored as a function of temperature which is shown in Figure 3 (a). The sudden fall in the intensity is identified as melting transition. The ratio D_L/D_S measured using DLS across the melting transition is shown in Figure 3(b). During melting of PNIPAM microgel crystals the ratio $D_L/D_S < 0.1$, indicating the deviation of dynamical criterion. In order to understand the reason for this deviation, mean square displacement (MSD) of microgel particle close to melting transition have been carefully analyzed with power law behavior ($\langle r^2(t) \rangle \propto t^\beta$). The MSD as a function of time for both PNIPAM microgel samples close to their melting are shown

in Figure 4(a). For the sake of comparison, MSD close to freezing of shear melted suspension of homogeneous particles (charged silica particles of diameter 120nm, $\phi = 0.0025$) is also shown in Figure 4(a). At long time intervals, usual diffusive behavior of MSD is observed (i.e. $\langle r^2(t) \rangle \propto t^\beta$ with $\beta = 1$) for PNIPAM microgels as well as silica particles. Whereas, for PNIPAM microgels, MSD at short-time intervals shows unusual behavior. For silica particles MSD is diffusive (i.e. $\beta \sim 1$) at short times whereas for PNIPAM microgels it is sub-diffusive ($\beta < 1$) at short times. Behavior of MSD at short times, for silica and PNIPAM microgel particles, is shown in inset to Figure 4(a) with corresponding β values obtained from power law fits (continuous lines). The subdiffusive behavior of MSD suggests that in the dense suspensions, motion of PNIPAM microgel particles is subdiffusive at short times. Hence, D_S cannot be extracted from short time MSD data. Dynamical criterion is defined for diffusive motion only. Thus, the lack of diffusive motion at short times explains the deviation of D_L/D_S at melting of PNIPAM microgel crystals.

The subdiffusive behavior of MSD for PNIPAM microgels at short time scales have been attributed to the overlapping / entanglement of the dangling polymer chains between neighbouring microgel particles in dense suspensions. Such entanglements of dangling polymer chains are depicted schematically in Figure 4 (b) for low ϕ sample S1 and Figure 4 (c) for high ϕ sample S2. As ϕ increases, value of β decreases which suggest increase in entanglement of dangling polymer chains with ϕ . These studies revealed that hairy structure of the shell of PNIPAM microgels have strong influence on the particle dynamics under dense conditions.

Rheology of dense PNIPAM microgel glasses

MSD for dense PNIPAM microgel glass also showed subdiffusive behavior at short times, suggesting the presence of entanglements of dangling polymer chains between neighbouring microgel particles in the glassy state. In order to look at the consequences of entanglements of dangling polymer chains between neighbouring microgel particles on the rheological (shear deformation and flow) behavior, we have studied the non-linear rheology of microgel glasses by subjecting them to large amplitude oscillatory shear. Figure 5 shows variation of storage modulus, G' and loss modulus, G'' with shear strain amplitude, γ_0 for PNIPAM microgel glass with $\phi = 0.70$, at 20°C. For lower values of γ_0 , both G' and G'' exhibit a plateau indicating the region of γ_0 over which PNIPAM microgel glasses show linear deformation behavior. In the plateau region, $G' > G''$, which suggests that the glass behaves as a viscoelastic solid for low γ_0 . On the other hand for larger γ_0 , G' comes down indicating the yielding of glass under applied shear. With increase in γ_0 , G' further comes down and crosses G'' . The value of γ_0 at which G' crosses G'' is defined as the yield strain. Beyond the yield point, $G' < G''$ indicating shear melting of the glass at large value of γ_0 .

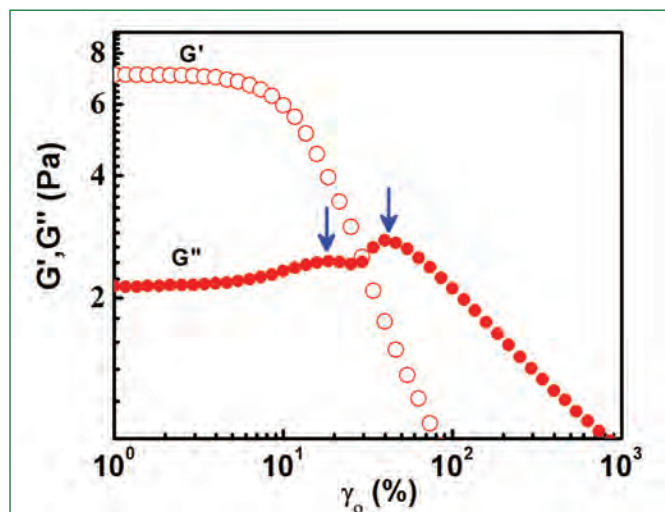


Figure 5: Yielding behavior of dense PNIPAM microgel glass ($\phi = 0.7$). Arrows indicate two step yielding at 20°C

Upon yielding, G' for PNIPAM microgel glasses show monotonic decrease with γ_0 , similar to that observed for glasses of hard spheres. On the other hand, G'' for PNIPAM microgel glasses exhibit two peaks at two values of γ_0 , in contrast to one peak observed in the case of hard sphere glasses. Single peak in G' for hard sphere glasses arises due to breaking of the near neighbor cages. Two peaks in G'' indicate that the yielding of PNIPAM microgel glass occurs in two steps. i.e. there exist a mechanism in addition to the cage breaking. Under the applied shear, entanglements of polymer chains between neighbouring microgel particles break giving additional mechanism for the yielding of PNIPAM microgel glasses. Thus, the two step yielding in PNIPAM microgel glasses arises due to i) breaking of entanglements of dangling polymer chains between neighboring PNIPAM microgel particles giving a peak in G'' at lower strain and ii) breaking of the near neighbor cages giving a peak in G'' at higher strain.

Above studies suggests that the soft and core-shell structure of PNIPAM microgel particles strongly influence their structural ordering, dynamics and shear flow behavior under dense conditions. These studies have implications in many practical applications of PNIPAM microgels. The observation of sequential blue shift in Bragg diffraction from PNIPAM microgel crystals implies their use as photonic crystals with tunable lattice constants. Microgels are used in many of the personal care products, which involves shear during their preparation and usage. Study of shear deformation of dense microgels is important towards fine tuning of their shear properties. Present investigations are based on temperature as a stimulus for PNIPAM microgels. For future studies, we aim at the study of response of PNIPAM microgels for different stimuli and modeling the corresponding interactions, phase behavior and dynamics.

Reported by

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Young Officer's FORUM

Experimental Simulation of Hydrodynamics of Mixing of Molten Salt and Cadmium

Several R & D programmes have been initiated at IGCAR for establishing the technology of closed metal fuel cycle with emphasis on fuel fabrication and reprocessing. Metal fuel allows a injection-casting fuel fabrication technique and electrorefining-based fuel cycle closure, together termed as pyroprocessing. Pyroprocessing promises simpler waste management, proliferation-resistance and much improved economics. The main steps in pyroprocessing of spent metallic fuel are electrorefining, cathode processing, salt purification/actinide extraction, metallic waste treatment and pin casting. The salt purification process is also called as actinide drawdown process. In this process, the electrolyte salt after electrorefining is purified by high temperature liquid-liquid extraction between salt (LiCl-KCl eutectic) and metal (cadmium) phase containing a suitable reducing agent.

Actinide draw down process

Actinide draw down process allows for recycling of the actinides and elimination of the fission products from the salt phase. Actinides up to 99.9% are recovered from the salt phase by this process. Figure 1 shows the schematic diagram of the process. The process, as described in Argonne National Laboratory reports, comprises of four basic steps:

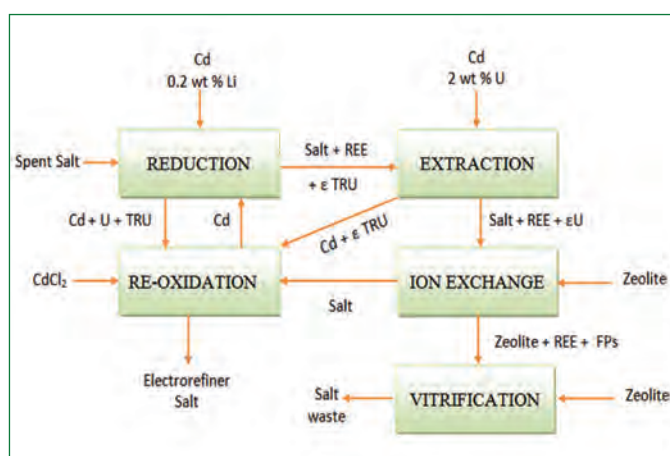


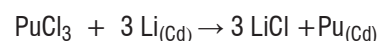
Figure 1 : Schematic diagram of actinide draw-down process



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Reduction Step

The salt containing the fission products and actinides in chloride form is placed in a high temperature centrifugal extractor in contact with an initial liquid cadmium metal phase containing 0.2 wt % of lithium (reducing agent).



The quantity of lithium is sufficient to extract 95–99% of the actinides while leaving the rare earth elements in the bath after two to three countercurrent extraction stages.

Extraction Step

The salt is then placed in contact with a fresh metallic cadmium phase containing 2 wt% U to extract the remaining traces of the actinides. Six to eight counter current extraction stages are necessary to extract 99.9 % of the remaining actinides, together with less than 20% of rare earth elements (REE). The uranium transferred to the salt as UCl_3 is recycled with the salt in the electrorefiner.

Ion Exchange Step

The salt flows through zeolite (4Å) beds where the fission products are substituted by cationic exchange for the initial potassium and lithium in the zeolites, which can accommodate up to 15 wt% fission products.

Re-oxidation Step

After elimination of the fission products, the salt is placed in contact with the metallic phase obtained from the extraction step. A strong oxidant (CdCl_2) is added to re-oxidize the actinides and transfer them to the salt phase, which is then recycled to the electrorefiner.

Experimental Simulation

The recovery of actinides in these extraction stages depends on the efficiency of the extraction equipment used. Multistage centrifugal and batch extractors were being developed for mixing the two phases in the actual hot cell applications at

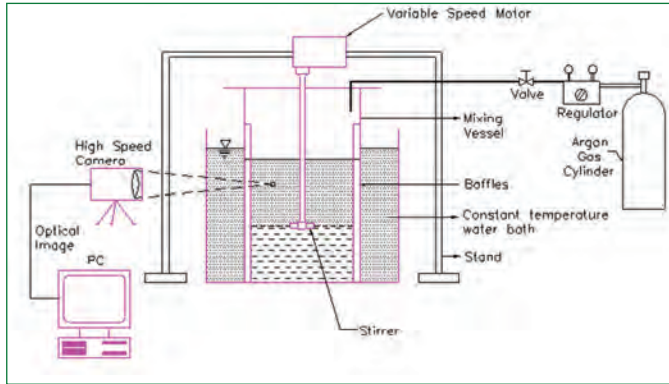


Figure 2: Schematic of the experimental set-up

Argonne National Laboratory. The study of mixing between the eutectic salt and the cadmium is very complex due to the large density difference (LiCl-KCl density = 1.5 g/cc and cadmium density = 8 g/cc), immiscible nature of the phases, high temperature (500°C) requirement of the process and high radioactivity associated with the fission products in the salt phase. The process of prediction of mixing behaviour either through actual experiments or through numerical simulation method alone is very difficult. Therefore, it is necessary to develop basic understanding of the hydrodynamic interactions involved in mixing the two phases using simulants at or near ambient temperature. Hence an experimental study was planned and conducted. The study is focussed to determine some of the characteristics of the resulting dispersion like critical impeller speed, drop size distribution, etc using simulants. The critical impeller speed for the fluid pair has been determined based on visual and imaging method. The drop size measurements have been carried out by adopting photography through vessel wall technique.

In the present investigation, water and Field's Metal (FM, a eutectic alloy of In, Bi and Sn) have been identified as the near ambient temperature simulants for molten salt phase and cadmium phase respectively. The kinematic viscosity of water and FM at ambient temperature is similar to that of molten salt and cadmium at 500°C respectively. Apart from that, these materials are non hazardous and easy to handle. Table 1 gives the comparison of properties of water and the FM respectively with eutectic salt and cadmium.

Figure 2 shows the schematic diagram of the experimental setup used and Figure 3 shows the snapshot of the setup. Standard geometric dimensions have been adapted. The mixing tank is 105mm in diameter, typical of mixing studies, and is made of borosilicate glass to allow for flow visualization and optical measurements. The baffles, constructed in the form of stainless steel stand, are 2 mm thick and 8 mm wide. Four bladed turbine and 3 bladed (pitched) turbine impeller of 40 mm diameter made of SS are used in the experiment. The agitation is provided by

Table 1: Comparison of properties of LiCl-KCl eutectic mixture and cadmium with their simulants.

S. No	Fluid	Melting point (°C)	Density (kg/m ³)	Viscosity (Pa.s)	Kinematic viscosity (m ² /s)
1	LiCl- KCl eutectic mixture at 500 °C	325	1551	0.00123	7.93×10^{-7}
	Water at 30 °C	0	995.65	0.000798	8.01×10^{-7}
2	Cadmium (500°C)	321	7820	1.84×10^{-3}	2.53×10^{-7}
	Field's metal	60	7880	$\sim 1.6 \times 10^{-3}$	2.03×10^{-7}

an IKA make overhead motor capable of operating at speeds in range of 0-2000 rpm. The water bath is used to keep the fluids at operating temperature of 65 °C (as dictated by the m.p. of FM which is 60 °C). The two walls of the bath are covered with glass to view the contents inside. Cover gas arrangement is provided, to inert the free space above the liquid level inside the vessel, to avoid undesirable reaction of molten FM with the contaminants (mainly oxygen) in water. A high speed (250 fps) FASTEC inline imaging camera, (focused on the mixing fluid) is used to monitor and capture the images of the evolving two phase dispersion. The camera is connected to a host PC to operate and store the images for future analysis.

The mixing vessel, filled with required quantity of FM and ultrapure water, is placed inside the water bath. The bath is programmed to raise and then maintain the temperature of the contents to 65 °C. Once the FM melts, it forms the separated layer below the water. The stirrer is fixed in the vessel and the argon gas is allowed to inert the free space. The agitation is provided and the contents in the vessel are monitored visually and through Imaging Camera-PC arrangement. Once the FM starts getting dispersed in water, the camera is triggered to record the images. The raw images are processed using MATLAB software.

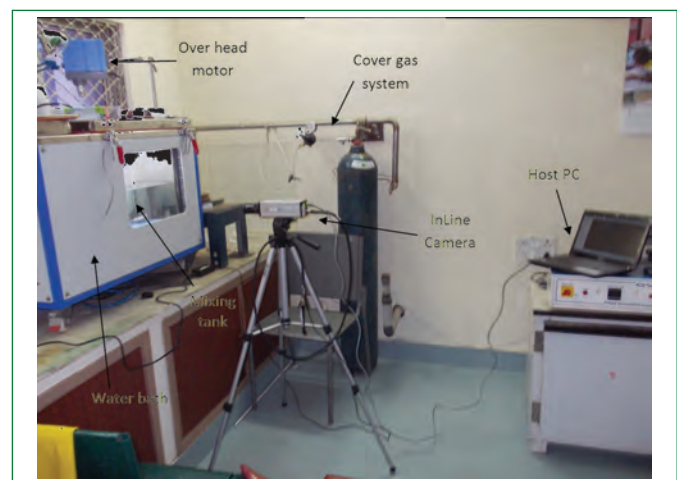


Figure 3 : Experimental set-up used

Critical impeller speed measurement for FM - water liquid system is an important parameter which determines onset of the production of the alloy water dispersion. Hence, for the determination of critical impeller speed, experiments were conducted with different volume ratios of the two phases and also different location of the impeller from the bottom of the tank. Since method of determination is visual, direct manual observation as well as observation through real-time imaging by inline camera is carried out. The agitation speed is varied in small increments so as to find the exact value at which dispersion is formed. Table 2 summarizes the experimental conditions and corresponding measured values of agitation speeds. It was observed that when the impeller is placed at the interface between the FM and water, the mixing zone becomes narrow and is confined to small region around the interface. Though there is turbulence at the interface even at lower rotational speeds of 800-1000 rpm and FM could be seen moving in chunks, with very few drops of the FM existing in the water phase. Hence, it was decided to keep the impeller just above the interface as done by many researchers for organic aqueous dispersions. As seen from the table, critical agitation speed needed for 4-bladed impeller is more compared to pitched blade impeller when the impeller is placed at the same height from the bottom of the mixing vessel. Also as the height of the impeller from the bottom of the tank is increased, the critical impeller speed increases.

The measurement of the drop size distribution in liquid-liquid dispersions even with photographic technique is a challenging task as enormous amount of raw data has to be processed. The images are being generated every 20 milliseconds for the recording duration of about 16 seconds for each experimental run. The image processing is done using MATLAB software. Figure 4 shows the images of the FM in water dispersion taken with inline

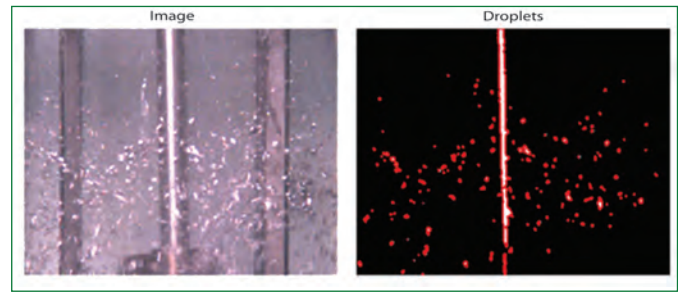


Figure 4 : Image of the fields metal water dispersion and its processed copy for drop size measurement.

camera and its corresponding processed image for count and size measurement.

Though about fifty experiments were conducted, data from six experiments were considered for drop size distribution. The pitched blade impeller was used in these experiments and the volume ratio of the FM to water was 21%. The drop size distribution is characterised by Sauter Mean Diameter (an average size of the drops based on the total volume and total surface area of the dispersed phase). Figure 5 show the Sauter Mean Diameter calculated over the time scale used in the analysis. In fact the curves indicate that the Sauter Mean Diameter is concentrated at one particular value with a fluctuating range of 0.1-0.2 mm. Hence, the time averaged value of the Sauter Mean Diameter has been taken to give more appropriate representation of the drop size.

Figure 6 and Figure 7 show the drop size distribution plots for the two sets of experiments. The drop diameter is plotted on the X-axis and the number fraction (ratio of number of drops of i^{th} size to the total number of drops) is plotted on the y-axis. The shape of the distribution curves is logarithmic for both of the two plots as was found by fitting distributions to the drop size data. The same distribution is followed

Table 2: Critical Agitation Speed Measurement at various experimental conditions

S. No	Volume ratio (Field's metal / water) %	Impeller type	Impeller location from tank bottom (mm)	Critical agitation speed (rpm)
1	5	Pitched blade	20	1000
2	10	Pitched blade	35	1250
3	21	Pitched blade	45	1000
4	21	Pitched blade	55	1350
5	21	4-bladed impeller	45	1100
6	21	Pitched blade	30 (interface)	800
7	30	Pitched blade	30 (interface)	900

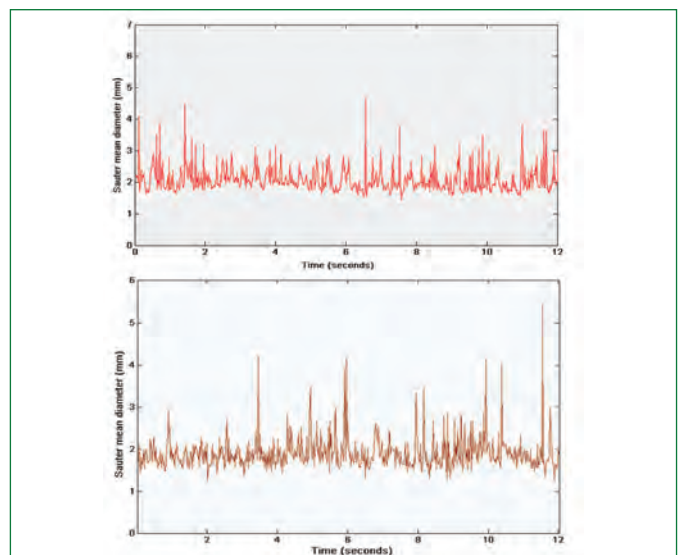


Figure 5: Evolution of sauter mean diameter with time at rotational speeds of 1400 & 1600 rpm

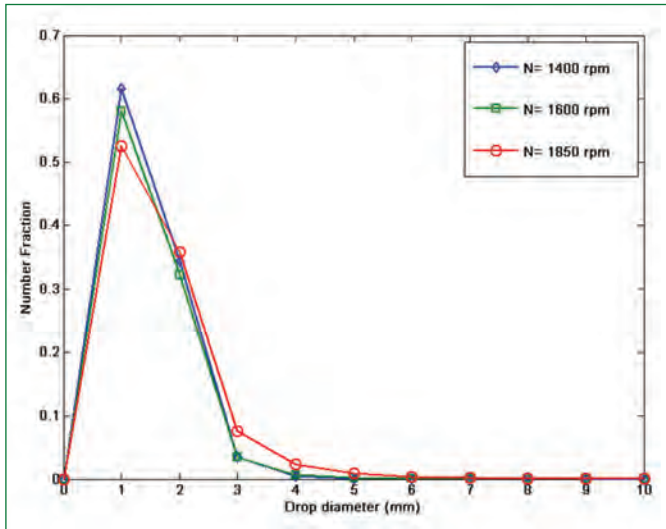


Figure 6 : Distribution of diameter of dispersed droplets (impeller at 15mm from the interface)

by drops at higher rotational speeds as investigated by many researchers. The particle size distribution is logarithmic in case of liquid-liquid system investigated here.

The prevailing droplet size distribution in a liquid-liquid system is controlled by many parameters such as impeller speed and configuration of the various components of the system. This is reflected in the previous plots shown above. The Sauter Mean Diameter was calculated as the time averaged value for each rotational speed. The effect of rotational speed (or N_{Re} , the impeller Reynolds Number, $\rho_m N d_i / \mu_m$) and impeller location on the Sauter Mean Diameter was determined. Figure 8 shows the variation of Sauter Mean Diameter with location of impeller and impeller Reynolds number. The impeller Reynolds number was calculated assuming mean values of viscosity and densities at hold up of 20%.

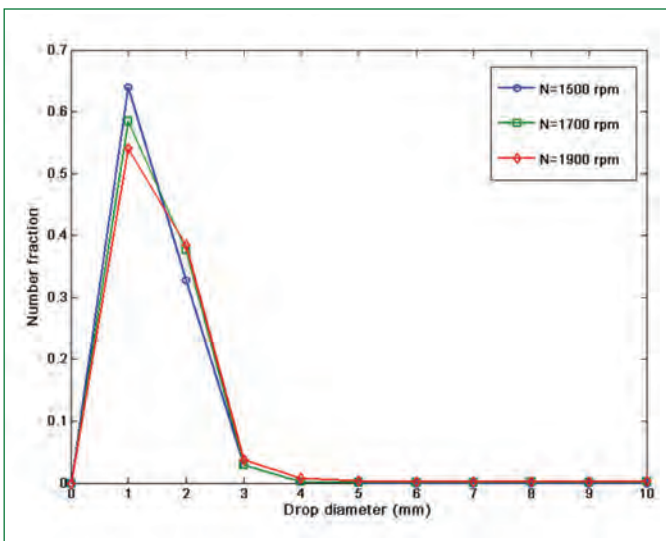


Figure 7 : Distribution of diameter of dispersed droplets (impeller at 20mm from the interface)

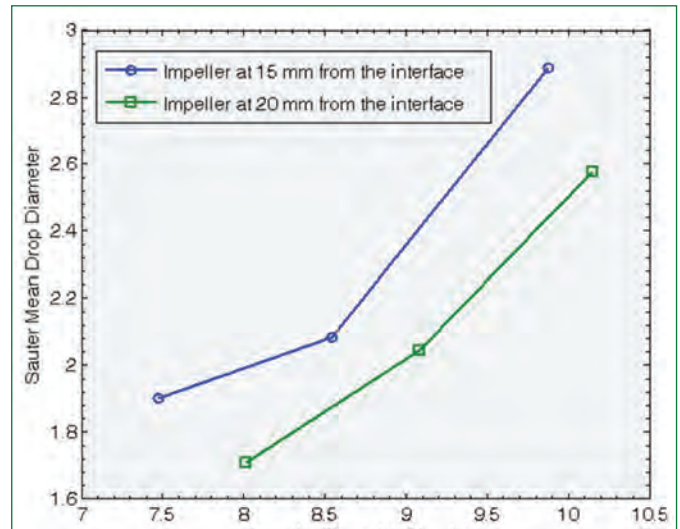


Figure 8 : Effect of Impeller Location and Impeller Reynolds Number on SMD

From the plots it is clear that the Sauter Mean Diameter increases as the rotational speed (or N_{Re}) of the impeller is increased. This result is in contrary, in one way, to data available in the literature where the Sauter Mean Diameter decrease as the impeller speed (or N_{Re}) is increased. However in the available literature the SMD has been calculated at fixed hold-up of dispersed phase. But in our case the hold-up of the dispersed phase is not fixed and it increases with increasing rotational speed (or N_{Re}) as evident from the drop size and count measurements. Hence, the effect of hold-up on the SMD is more pronounced compared to the impeller Reynolds number for the cases studied here. The SMD decreases as the impeller is moved away from the interface. The effect is explained by observing the drop population of the experiment, which indicates hold- up is less compared to when impeller is near to interface.

The mixing of Field's Metal and water results in formation of coarse liquid dispersion with 1.5-3mm FM drops dispersed in water (continuous phase). The dispersion is effectively formed beyond the rotational speeds of 1000 rpm. The drop size distribution curve is logarithmic and the curve shifts towards higher drop sizes with increase in impeller speed. The SMD increases with the impeller speed and decreases with increase in distance between impeller and the interface. The axial flow type agitators are more suitable for mixing such type of fluid systems. Similar behaviour is expected to be observed in mixing molten salt and cadmium at 500°C. The results from the experiment have contributed significantly for the development of high temperature mixing devices for Actinide Drawdown Process.

Reported by
Asif Ahmad Bhat, Fast Reactor Technology Group

Young Researcher's FORUM

Significance of Thermo-Mechanical Constitutive Modeling in Thermal Ratcheting Prediction

One of the most critical components of nuclear reactor such as Prototype Fast Breeder Reactor, is the main vessel. It contains large quantity of radioactive liquid sodium at high temperature. Any failure or damage to the main vessel may lead to serious consequences. Safety vessel is provided for collecting sodium that leaks during the event of any sodium leakage from the main vessel. The gap between the main vessel and the safety vessel is filled with nitrogen. The gap is ~ 300 mm to permit robotic visual and ultrasonic inspection of the vessels. Any change in the gap or deformation of the main vessel may affect the free movement of inspecting device and the deformation beyond a prescribed limit and affects the integrity of the vessel. The main vessel experiences thermal cycling near the vicinity of hot sodium free level, which varies at different operating conditions. During free level variation, the sodium temperature also varies. Thus, a moving temperature front with changing peak temperature simulates the realistic thermal cycling. This type of thermal cycling is responsible for the thermal ratcheting of main vessel resulting into an inward or outward radial deformation, which may grow progressively beyond the prescribed limit or until failure.

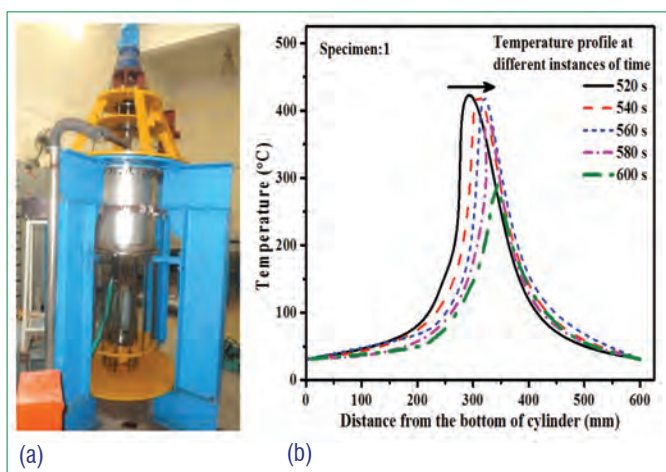


Figure 1: (a) Thermal ratcheting test setup (b) profiles of the moving temperature front recorded by thermocouples



Shri Ashutosh Mishra did his M. Tech in Mechanical Engineering from IIT Varanasi. He joined IGCAR as DGFS PhD Fellow in February, 2011 and carried out his doctoral work in Reactor Design Group under the guidance of Dr. P. Chellapandi. His doctoral thesis titled "Ratcheting of thin shells under thermomechanical loading: Development of a code for predicting ratcheting with thermomechanical interactions" has been submitted to Homi Bhabha National Institute. His areas of research are, structural integrity, constitutive modeling, thermo-mechanical material behavior.

The choice of a constitutive model plays a significant role in the prediction of ratcheting. Thermal cycling due to concurrent change in peak temperature during free level variation requires thermo-mechanical model for accurate prediction of ratcheting. In addition to this, for a user defined constitutive model, the implementation of plasticity integration scheme is another difficulty which governs the accuracy of ratcheting prediction.

Thermal Ratcheting Prediction

To simulate the thermal cycling due to free level variations (Case-A) as in the main vessel of pool type reactors, a thermal ratcheting test facility is developed as shown in Figure 1 (a). The cylinder specimen is fixed while a level oscillator arrangement provides the free level variations. Level variation is simulated by using a stepper motor arrangement with the appropriate speed reduction gearbox system. The speed of level variation can be adjusted using a variable-frequency drive (VFD) controller. To record the transient thermal loading response, thermocouples were welded outside the cylindrical shell specimens along its height. Non-contact type laser sensors were deployed along the height of the cylinder to capture the radial growth. The outer surface of the Specimen 1 was heated locally up to 450 °C using induction heater, which was placed above the free level of water. The water level in the cylinder was varied up to 70 mm with a cycle time of 240 s. Specimen 2 was subjected to similar loading with peak temperature of 550 °C, cycle time of 460 s and level variation of 45 mm. The temperature variation along the height of the Specimen 1 captured by the thermocouple at different instants of time is given in Figure 1(b).

Thermal loading for 20 and 16 cycles were applied and laser sensors were used to capture the radial growth of specimens 1 and 2. It is to be noted that, there is no change in peak temperature during level variation, i.e. temperature of induction heater is kept constant. Due to high temperature, significant thinning in

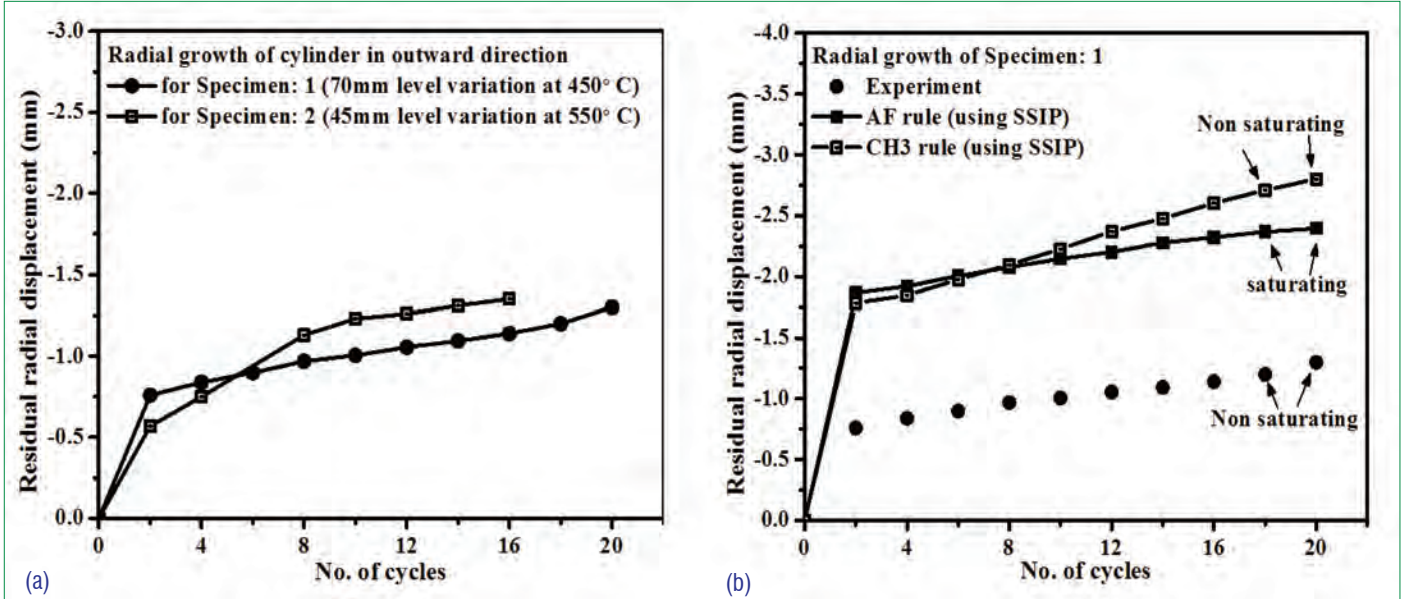


Figure 2: (a) Residual radial displacement for Specimen 1 and 2 (b) Residual radial displacement for Specimen 1 using AF and CH3 rules

specimen 2 was observed and the test was stopped at 16th cycle. The residual radial displacement with the number of cycles are shown for both the specimens in Figure 2a. Although, initially, for a few cycles, lower residual radial displacement is noticed for specimen 2, but rapid growth is observed thereafter compared to specimen 1 in spite of being operated for reduced level variation (or reduced traveling length of the temperature front).

The non saturating ratcheting data for specimen 1 is compared with the numerical results to demonstrate the performance of Armstrong-Fredrick (AF) rule and Chaboche three back stress (CH₃) rule as shown by Eq. (1) and Eq. (2). The material parameters are identified by conducting strain rate jump test at 2E-4/s and 2E-3/s and low cycle fatigue tests at a constant strain rate of 3E-3/s. The numerical analysis is done using the identified parameters and implementing Simplified Semi-implicit Integration Procedure (SSIP). It is evident from Figure 2(b) that the numerical predictions from AF rule is approaching saturation (shakedown) while ratcheting is noticed in case of CH₃ rule that recognized the experimental progressive ratcheting i.e. non saturating behavior aptly.

$$\dot{X} = \frac{2}{3} C_d \dot{\epsilon}^P - \gamma \dot{X}^P \quad (1)$$

$$\Delta X = \sum_{i=1}^M dX_i = \frac{2}{3} C_i d\epsilon^P - \gamma_i X_i \Delta P \quad (2)$$

$$\dot{X} = \frac{2}{3} C_i d\epsilon^P - \gamma_i X_i \dot{P} + \frac{\partial C}{\partial T} \frac{X}{c} \dot{T} + \frac{\partial \gamma}{\partial T} X P \dot{T} \quad (3)$$

Thermomechanical Ratcheting Prediction

The FE model of the specimen 1 is subjected to a traveling temperature front with the concurrent change in peak temperature simulating a linear increase and decrease of temperature of

induction heater with level rise and fall respectively (Case-B). Peak temperature of moving temperature front varies with time from 250- 450 °C during free level rise by 70 mm as shown in Figure 3

The significance of thermo-mechanical constitutive modeling is demonstrated by using temperature rate terms (TRT) and linear ratcheting effect of CH₃ rule. The thermal ratcheting deformation is (non saturating) is predicted using CH₃ rule with TRT as in Eq. (3). Corresponding results of progressive deformation in the radial direction using isothermal material parameters for CH₃ rule after the intervals of five cycles are shown in Figure 4. The effect of this type of load is such that initial radial outward deformation mode (expansion) changes to radial inward deformation mode (contraction) which is captured by CH₃ with TRT. After 15th

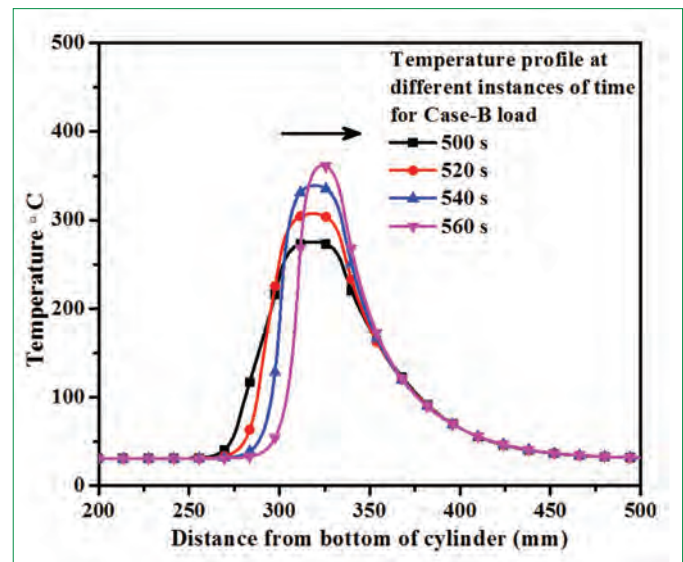


Figure 3: Moving temperature front with increasing peak temperature

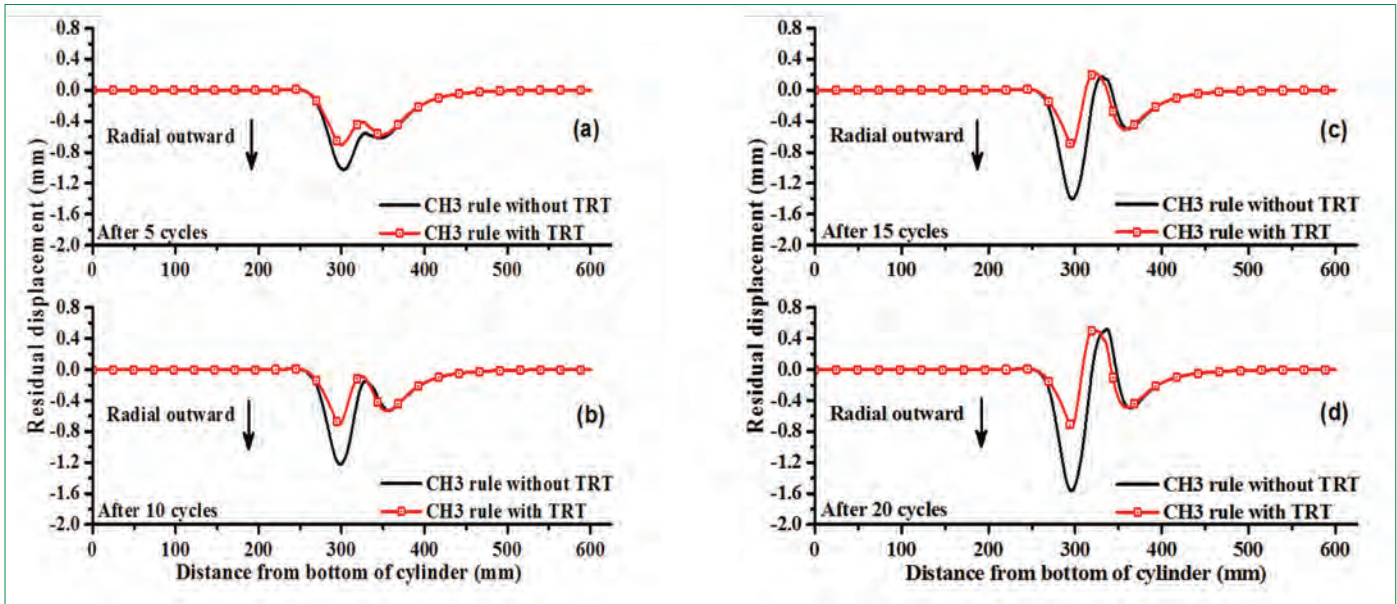


Figure 4: Growth in residual radial displacements for Case-B load corresponding to CH₃ rule with and without TRT after (a) 5 (b) 10 (c) 15 and (d) 20 cycles

cycle, no increase in radial growth (expansion) is seen for CH₃ with temperature rate terms, instead, an increase in radial inward deformation (contraction) is noticed in Figure 4 (c) and (d).

The deformed cylinder after 20 cycles due to thermal ratcheting is shown in Figure 5 presenting the significance of employing TRT in the constitutive model. The limitation of hardening rules without

TRT is clearly visible in these results, which failed to reveal the change in the mode of deformation from expansion to contraction. Contrarily, the inclusion of TRT in CH₃ rule predicts the change in deformation mode distinctly. After the 20th cycle, the extent of inward growth (contraction) is higher compared to the outward growth (expansion) in Figure 5 (b), where U1 is the residual radial displacement in meters. This demonstrates the significance of TRT while predicting the dynamic behavior of the cylindrical shell under thermomechanical loadings. The proposed approach (including TRT in CH₃ rule) successfully captured the change in deformation mode (expansion to contraction) which is extremely important to predict the gap between the main vessel and safety vessel for free movement of inspection device.

The results reported here for the thermal ratcheting behavior of SS 316 L stainless steel cylindrical shells at 450 and 550 °C demonstrate the strong influence of changing the traveling lengths of moving temperature front. Comparison of experimental and numerical results of radial growth in the cylindrical shell highlights the suitability of CH₃ rule for predicting progressive ratcheting behavior. Further, the significance of thermo-mechanical loading that simulates the changes in sodium pool temperature during free level variations in the main vessel of Sodium Cooled Fast Reactors has been presented. Under such loading conditions, the material constitutive model which can successfully capture the change in the deformation mode (expansion to contraction), requires TRT in the kinematic hardening rule. The present study is an important contribution towards the prediction of ratcheting with thermo-mechanical interaction.

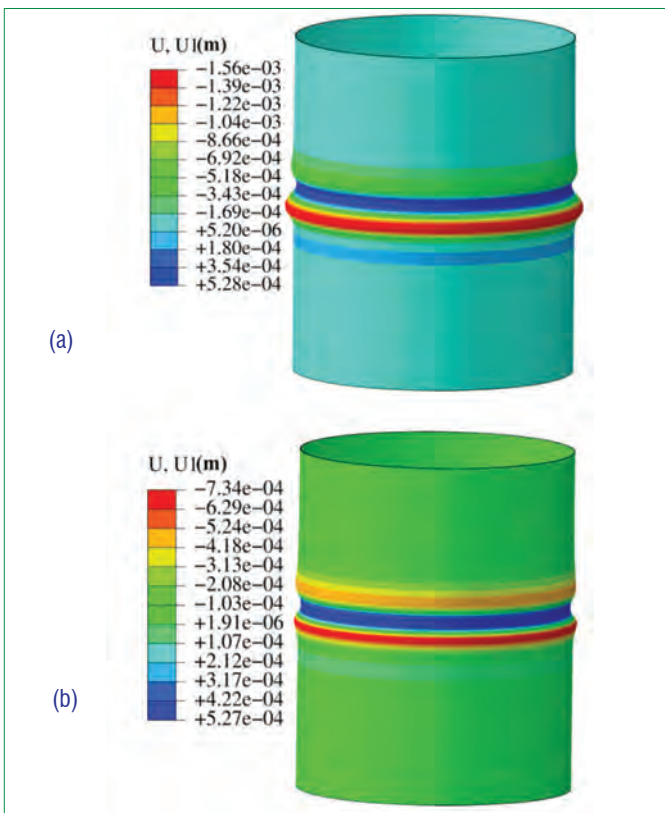


Figure 5. Deformed cylinders after 20 cycles corresponding to (a) CH₃ rule without TRT and (b) CH₃ rule with TRT

Reported by
Ashutosh Mishra, Reactor Design Group

Conference and Meeting Highlights

Diamond Jubilee Celebrations of the Department of Atomic Energy at Kalpakkam



Dr. R. K. Sinha, Chairman, Atomic Energy Commission & Secretary, Department of Atomic Energy at the DAE Diamond Jubilee Commemorative Structure

Towards commemorating the six decades of remarkable performance of our Department a series of lectures, exhibitions, visits to facilities at IGCAR for students from various colleges and educational institutions and outreach programmes are being organized as a part of the celebration. Some of the initiatives undertaken during the quarter, April-June, 2015 are highlighted below:

Inauguration of DAE Diamond Jubilee Commemorative Structure and Sand Sculpture:

DAE Diamond Jubilee Commemorative Structure was designed, created and was remotely unveiled by our Chairman, Dr. R. K. Sinha during his visit to IGCAR on 19 May 2015

A Sand sculpture exhibition was organized at the DAE Township, depicting the picture of Dr. Homi Bhabha along with DAE logo. This sculpture was designed by Shri Gajendran, sand sculptor from Kelambakkam on 19 May 2015.

State-level Quiz Competitions:

IGCAR and Indian Nuclear Society, Kalpakkam Branch has been conducting quiz competition cum exhibition the districts of Krishnagiri, Vellore, Villupuram, Vriddhachalam and Tiruvannamalai at the Arunai Engineering College, Tiruvannamalai, with participation from twenty one Science & Arts colleges in these regions during June 25-26, 2015.

State level Inter College Quiz competition cum exhibition was organized at Kongu Arts and Science College, Erode during May 15-16, 2015 with the participation of students from sixteen colleges from Coimbatore, Namakkal, Erode and Salem districts. Another programme organized at Sree Sevugan Annamalai College, Devakottai organized during June 29-30, 2015, had participation of PG & UG students from fifteen colleges in Ramanathapuram, Madurai, Pudukottai, Vriddhachalam, Karaikudi and Devakottai.

Outreach & Awareness Programmes:

Several exhibitions were organized across Tamil Nadu by IGCAR. These exhibitions were useful in educating the public about nuclear energy and the activities of DAE. It also helped in dispelling the fear about the radiation and the activities of the Department.

Visits to various facilities at IGCAR for students from various colleges and educational institutions are being organized every week. In this quarter, the following teams visited us.

S No.	Date	College / Institution
1	07 April, 2015	Naval War College, GOA
2	17 April, 2015	Dr. M.G.R. Educational and Research Institute, Chennai
3	21 April, 2015	University of Madras, Chennai
4	24 April, 2015	VIT, Chennai Campus
5	30 April, 2015	State Government Teachers
6	15 June, 2015	Madras University

Visit of Dignitaries

Dr. R. K. Sinha, Chairman, Atomic Energy Commission & Secretary, Department of Atomic Energy visits IGCAR



Dr. R. K. Sinha, Chairman, Atomic Energy Commission & Secretary, Department of Atomic Energy delivering the first "N. Srinivasan Memorial Lecture"

Dr. R. K. Sinha, Chairman, Atomic Energy Commission & Secretary, Department of Atomic Energy visited IGCAR on **19 May, 2015** to participate in a multitude of important official engagements. To mark our respect and tribute to the eminent scientist and founder director of IGCAR (then Research Reactor Centre), Late Shri N. Srinivasan, a memorial lecture was organized at IGCAR. Dr. Ratan Kumar Sinha, delivered the first "**N.Srinivasan Memorial Lecture**" on the topic "**Nuclear Power : Past, Present and Future**".

Technology Day is being organized every year at IGCAR in order to encourage and motivate the technical fraternity to come forward and present their ideas. Dr. Sinha also distributed certificates to the recipients of Best Presentation Award of the Technology Day Meet 2015 before his lecture.

ECIL has been collaborating with IGCAR in many projects. A memorandum of understanding was signed with ECIL on furthering the progress with respect to Wireless Sensors Networks during the visit of Chairman.

During his visit to IGCAR, Dr. Sinha remotely unveiled the DAE Diamond Jubilee structure located at intersection point of major Units at Kalpakkam (IGCAR, MAPS and BHAVINI) which was evolved as a part of the commemoration of Diamond Jubilee celebration depicting the concept of 60 years of achievement of DAE.

Dr. R. K. Sinha also visited Fast Reactor Fuel Cycle Facility and BHAVINI. He also visited the sand sculpture erected at the beach sands of Kalpakkam as part of Diamond Jubilee celebration. This sculpture depicted Dr. Homi Jehangir Bhabha embedded on DAE Logo was carved by Shri Gajendran, a sand sculptor from Kelambakkam.



Dr. R. K. Sinha, Chairman, Atomic Energy Commission & Secretary, Department of Atomic Energy, Dr. P. R. Vasudeva Rao, Director, IGCAR and senior colleagues of the Centre at the sand sculpture exhibition

Visit of Dignitaries



Delegations from United States Nuclear Regulatory Commission led by Dr. William Ostendorff with Dr. T. Jayakumar, Director, MMG and senior colleagues of the Centre

A delegation from United States Nuclear Regulatory Commission led by Dr. William Ostendorff, Commissioner, US Nuclear Regulatory Commission visited the Centre during **May 4- 5, 2015**. After a meeting with Dr. T. Jayakumar, Director, MMG and other senior colleagues, the delegation visited the Fast Breeder Test Reactor, Radio Metallurgy laboratory, facilities in Fast Reactor Technology Group and Structural Mechanics Laboratory. The team also visited Madras Atomic Power Station and construction site of Prototype Fast Breeder Reactor.



Prof. Ghanashyam Date, Professor, IMSc, Chennai, delivering the IGC Colloquium

Prof. Ghanashyam Date, Professor, IMSc, Chennai, delivered the IGC Colloquium on " General Relativity: A Hundred Years Later", during his visit to the Centre on **May 12, 2015**

Visit of Dignitaries



Dr. C.B.S Venkataramana, Additional Secretary, during his visit

Dr. C.B.S Venkataramana, Additional Secretary, DAE visited the Centre on **30 June, 2015**. During his visit, he had visited Fast Reactor Fuel Cycle Facility, Fast Breeder Test Reactor, Sodium Chemistry Laboratory & Metal Fuel Fabrication Laboratory at Chemistry Group and PFBR Simulator at EIRSG

Awards & Honours

Dr. T. Jayakumar, MMG has been bestowed with “**VA Chandramouli Award**” by the Indian Society for Non-destructive Testing, Hyderabad Chapter - award received on April 02, 2015

Dr. M. Sai Baba, has been elected as a **Fellow of the Academy of Sciences, Chennai** on April 10, 2015

Dr. U. Kamachi Mudali is awarded **AICTE-INAE Distinguished Visiting Professorship** by INAE, New Delhi for the year 2015-16.

Dr. Rani P. George has been elected as a **Fellow of the Indian Institute of Metals**.

Dr. Rani P. George received **Shri. S.K. Seshadri Memorial Mascot National Award**, 2015 from Electrochemical Society of India, Bangalore in the area of corrosion and electrochemistry.

Ms. K. Kamali has received the “**Dr. K. V. Rao Research Award**” for the year 2014 -15, in Physics for her research work titled “**Selective Soft Mode Frustration in $\text{KMn}[\text{Ag}(\text{CN})_2]_3$ Single Crystals Studied by Raman Spectroscopy and First-Principles Calculations**” from Dr. K. V. Rao Scientific Society

Best Paper Awards

Development of SiC coating by pack cementation as interlayer over graphite for deposition of yttria by plasma spray process

Shri H. Thirunavuakarasu, Shri E. Vetrivendan, Shri Ch. Jagadeeswara Rao, Dr. C. Mallika, Shri R. Subramanian and

Dr. U. Kamachi Mudali

Natl. Symp. on Advances in Materials and Processing (NSAMP-2015), PSG College of Technology, Coimbatore, May (2015).



Painted stork

Dr. M. Sai Baba,

Chairman, Editorial Committee, IGC Newsletter

Editorial Committee Members: Dr. K. Ananthasivan, Shri M.S. Chandrasekar, Dr. N.V. Chandra Shekar, Dr. C. Mallika, Shri K. S. Narayanan, Shri V. Rajendran, Dr. Saroja Saibaba and Dr. Vidya Sundararajan