‘Greening’ undergraduate chemistry laboratories in Mumbai

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The concept of ‘Green Chemistry’ has caught the imagination of all chemists, including us chemistry teachers. However, while we are enthusiastic about teaching and illustrating the twelve principles of Green Chemistry in our theory classes, we appear to be totally oblivious to the lack of ‘green’ in our laboratory practices. Here we look at some of the issues involved and suggest some simple measures which could improve our laboratory functioning.

Ever since the 12 principles of Green Chemistry were introduced by Anastas and Warner[1] in 1998, a lot of work has been done towards development of green procedures in chemistry. Several reviews on the topic are available in the literature[2–4], and entire journals like *Green Chemistry*, *Green Chemistry Letters & Reviews* and many more are dedicated to research in this area. In addition, several conferences have been organized all over the country to highlight the importance of green chemistry for sustainable development. The question is how much of these green principles are actually practiced in our college laboratories. In reality, it is easy to find college undergraduate chemistry laboratories led by the thick fumes and noxious odours emanating from them. These labs also generate large quantities of toxic liquid and solid waste. Besides the pollution caused, other areas of concern involve the use of hazardous chemicals, the large scale of experiments with the consequent waste of chemicals and the waste of water, fuel and electricity. Also, our syllabi need to be updated keeping in mind the tenets of ‘Green Chemistry’. Finally, and most importantly, the safety and long-term health implications of our laboratory activities for both staff and students need to be given serious attention. Here some suggestions for improvement are made with reference to the above-mentioned problems.

Infrastructure. Chemistry laboratories can and should be bright and pleasant places to work in. A well-maintained laboratory with a display of the Periodic Table, useful chemical data, important single point instructions to encourage good laboratory practices (GLP) and important safety instructions would improve students’ performance and encourage lab discipline. Portraits of famous chemists displayed on laboratory walls would serve to inspire students. All instruments should have charts including standard operating procedures (SOPs) and simple trouble-shooting measures displayed in close proximity to the instrument. The laboratory should be designed to save as much time as possible. Colour coding of side-shelf chemicals according to their safety/toxicity with accompanying colour-coded lists would help in easy location of chemicals. Most importantly, no effort should be spared to reduce air pollution in the laboratory. It is imperative to ensure continuous air flow from the windows to the exhaust system in the laboratory. Every laboratory should ensure that exhaust fans and fume hoods are working and that they are serviced regularly to maximize their efficiency. It is important to mention here that since college fume hoods do not use scrubbers, the exhaust fans and fume hoods merely clear the laboratory of gaseous emissions and release the toxic fumes into the environment outside the building. This is not really an acceptable method of disposal. It is more important therefore that efforts should be concentrated on minimizing the generation of toxic fumes and sensitizing students to the harmful effects of these emissions. Finally because of the unavoidable build up of acid fumes in the laboratory and the consequent corrosion of metal pipes, taps, etc., it is advisable to maintain some appropriate ventilation when the laboratory is closed especially for long periods. We have found it useful to keep one or two meshed windows open and to cover burners and taps with paper during long vacation closures.

It is pertinent to mention here that in many colleges, the laboratory work in three shifts from 7.00 a.m. to 5.00 p.m., catering to nearly 170 students per day, which includes the UG and junior college students. While catering to such large numbers, it is not possible to provide a proper hood where all the students can perform experiments. The only solution may be to plan experiments that are suitable for large numbers of students working in laboratories with minimum exhaust facilities and it is here that curriculum changes can help.

Curriculum changes. Every experiment included in the course must be viewed in the context of the principles of ‘Green Chemistry’. For example, some qualitative analysis tests such as some of the dry tests and preparation of acid extracts as also extraction of metal from ores and several organic preparations currently in our syllabi generate substantial amounts of toxic gases and must be reconsidered and replaced if possible.

A task force set up by DST has developed a useful monograph with the objective of suggesting ‘modifications to the hazardous Laboratory Experiments, currently practiced by the students in the present syllabus’[5]. Several useful suggestions are included in this monograph for developing and implementing ‘greener’ experimental procedures. It is also essential that newer ‘green’ experiments are included in our syllabi even if they cannot be included in the examination due to time constraints. Experiments using green reagents, solvents, processes and catalysts must be included as project work to be recorded in the journal so as to familiarize students with these modern techniques. Finally, while it may not be initially attractive, it is time to consider replacing some wet chemistry experimental work with other options like more instrumental work, working with models and even computer simulations of experiments to achieve maximum benefit for students with minimum pollution and expenditure. These initiatives must be considered in light of the large number of students being catered to, as mentioned above.

Waste management and disposal. We have so far had a very casual attitude to waste, paying little or no attention to its reduction or disposal and it is high time this attitude changed. An important

initiative towards minimizing liquid and solid waste is reducing the scale of experiments. While there has been some attempt to reduce the scale of experiments by introducing semi-micro and micro techniques of qualitative analysis, there is still scope for reducing scale in our quantitative work by reducing both concentrations and volumes used. We have found that it is possible to work with approx. 0.2 N solutions in iodometric titrations without affecting the sharpness of the end-point. Similar efforts to determine the lowest concentrations appropriate for other undergraduate experiments must be undertaken. Reduction in volumes will necessitate some initial expenditure on new glassware but this would definitely be offset by the savings on chemicals and water. Standard flask volumes could be reduced to 50 cm^3, burettes to 10 cm^3 and pipettes to 5 cm^3 for regular use. Also quantities used for organic and inorganic preparations could be scaled down to 0.5 g or less. Another useful strategy for saving chemicals while reducing waste is the planning of experiments to reuse and recycle chemicals by designing experiments accordingly and by collecting the chemicals separated and purified by students and reusing them. Besides reducing waste, these measures would contribute significantly to lesser use of chemicals and lower budgetary requirements.

While every attempt must be made to reduce waste, the disposal of unavoidable waste also requires consideration. Experiments generating toxic gaseous emissions should be carried out in a fume hood with a trapping device. Common solid and liquid waste not regarded as harmful can be disposed of safely in the normal trash or drain. This includes non-hazardous substances which are not inflammable, corrosive, highly reactive or toxic. However, waste segregation must be made mandatory and a proper system must be introduced for regulation of disposal of toxic waste with the help of the municipal authorities.

Conservation of resources. Water is a resource that is not respected in our laboratories. Experiments requiring the use of reflux condensers by large number of students result in a huge waste of water. A simple rubber tube connection of inlets and outlets of four reflux condensers would substantially lessen the use of water. Another practice which needs to be phased out completely is the use of water pumps for suction filtration. Plumbing systems especially leaking taps must be repaired and maintained regularly. Finally, where possible water should be collected and used for other appropriate purposes.

Fuel and electricity are also resources that must be saved. Design and scale of experiments must be planned to minimize their use and students must be trained to close gas taps and switch off electrical equipment when not in use.

Safety in our laboratories. Safety is an important and integral part of green laboratory practices as stated in the last principle of 'Green Chemistry'. Besides the standard measures of planning safer experiments, ensuring the proper functioning of firefighting equipment, maintaining emergency medical supplies, avoiding pollution and adopting proper waste disposal methods, it is imperative that we implement the following preventive safety measures. First, no student should be permitted to work in the laboratory without a lab coat and protective goggles. Further, students must be made aware in advance of any hazards they might encounter while performing a particular experiment and they should have referred to the MSDS sheets of all chemicals involved in their lab work.

An important initiative to help implementation of the suggestions in this article is the organization of training sessions for staff, both teaching and support, and students to sensitize them to the health and environmental consequences of our laboratory work and to encourage them to think out and suggest 'green' practices that could be adopted. It is also essential to convince college managements of the need and long-term benefits of the expenditure involved.

In conclusion, it is in the best interests of the chemistry community for chemistry teachers to make every effort to include 'green' practices and procedures in laboratory work and to inculcate 'green' habits in students who will be the chemists and chemistry teachers of tomorrow. It is only when teachers and more importantly students are convinced of the need for change that we can hope to make the practice of 'Green Chemistry' a reality in laboratories and other chemistry-related industries.

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2. Clark, J. H., *Nature Chem.*, 2009, **1**, 12–13.
3. Reed, S. M. and Hutchison, J. E., *J. Chem. Educ.*, 2000, **77**, 1627–1628.
4. Ahluwalia, V. K. and Kidwai, M., *New Trends in Green Chemistry*, Springer, Berlin, 2004.
5. Monograph on Green Chemistry. Laboratory Experiments. Green Chemistry Task Force Committee, DST; http://www.dst.gov.in/green-chem.pdf

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