Growing Safety Challenges in Research Laboratories and Pilot Plants -

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Abstract

The risks posed by laboratory and pilot plants are unique and critical. Volumes of the hazardous materials handled in the above locations are often compared with the ones used in storage and manufacturing premises and considered to be safe with out requiring extra precautions. However the novel operations and processes used in such facilities, high operation density of equipment and chemicals in the restricted area, unproven or changing technology, lack of safety related information due to developmental stages and to protect confidentiality, over confidence of personnel, wastes generated by such facilities, use of sophisticated instruments etc throw safety challenges to the managers of such facilities. The increasing number of accidents and resulting injuries and property damages in the laboratories and pilot plants all over the world is testimony to the above fact. Of late seven strategy concept of safety management is being promoted for the pilot plants by the safety specialists. The key strategies suggested include properly conducted preconstruction safety reviews; leak tight design and construction; close attention to area electrical classification; well-designed ventilation; well-planned storage; properly conducted maintenance; and strictly followed procedures for the control of change. With the increased thrust to research and development, innovation ,quality control development in each sector and outsourcing of technological development oriented activities to developing countries like India it is essential that the risks at Laboratories and Pilot plants are assessed and properly controlled to protect lives, property and environment.

Research & Development is considered to be very important and crucial function by various industries. With the increasing competition in the business these Research and Development blocks have been identified to be houses of invention and hopes of future. While laboratories carry out various experiments and analysis with respect to new products, processes, tests etc. scale up from laboratory to plant has been a difficult problem in the chemical industry throwing up challenges for the chemical engineering professionals. Pilot plants are considered to be the important tool for tackling the scale up problems. Pilot plants principally assist the scale up of the process design rather than the mechanical design. For example the reaction conditions are studied keenly than the pump specification. As L.H. Baekeland suggests pilot plants operate on the principle “Make your mistakes on a small scale and your profits on a larger scale”. An accident in laboratory and pilot plant can be on a smaller scale than the one on the plant, however it can cause injuries and loss of lives. The direct property damage can also be significant

because of the concentration of high value equipment and instrument with in the restricted area. Consequence losses can be significant as it interrupts the scale up process and it may take a considerable time reconstruct similar facility which is not of standard type. Accidents are reported in research and development facilities frequently. The explosion accident that took place in the pilot plant (Refer box item 1) of chemical factory in Japan exhibits the hazard potential of similar facility.

Box item 1
Fire in an electrical graphitization furnace for carbon fiber production
Date : May 6, 1990
Place : Kawasaki, Japan
Type of Industry: Chemical
At research and development facilities for pitch-based carbon fibers, a fire occurred at an electrical graphitization furnace for carbon fiber production where spun pitch fibers were baked at a high temperature. A crack was caused in the post nozzle by stress corrosion due to the chlorine concentration of cooling water and stress concentration. Cooling water leaked into the furnace, a water gas reaction between water and carbon occurred, and carbon monoxide and hydrogen were formed. It is presumed that these flammable gases ignited and burned outside the furnace, and a fire started.

Overview of Hazards

Research and Development facility generally consists of laboratory and pilot plant. Laboratory is a facility where the containers used for reactions, transfers, and other handling of chemicals are designed to be easily and safely manipulated by one person. It is a workplace where chemicals are used or synthesized on a non-production basis. Pilot plant is an experimental assembly of manufacturing equipment for exploring process variables or for producing semi-commercial quantities of materials. Various chemicals that pose fire, explosion, toxic and corrosive hazards to the people are handled in the above facilities. Though the quantities of the chemicals may not be as comparable with that of the commercial plants the quantity handled in the facilities are capable of creating significant hazards. In one of the accidents that took place in the laboratory of a refinery a chemist was seriously injured while doing simple titration activity. Laboratories also witness fires due to improperly maintained ignition sources(Refer box item 2) In addition to the inherent hazards of chemicals handled the following are the unique hazards of laboratories and pilot plants:

- Elevated temperature and pressure
- High density of operating equipment
- Untested processes or technology
- Switching operations
- Non standard equipment

Elevated Temperature and Pressure

Significant volumes of flammable materials are handled at elevated temperatures and pressures as part of new process. The hazards of the chemicals increase in many folds during such conditions. In some cases the explosions and run away reactions are also possible. While most pilot plants deal with only small volumes of these materials at a given time, the overall quantity of flammable and combustible materials used and stored in most pilot plant areas is far from trivial. The autoclaves and pressure vessels used in the pilot plant are left out from the purview of periodical testing and inspection by the factory management and authorities making them vulnerable to failures and explosions when they are used for the experiments and tests.

High Density of the equipment

In comparison with full-scale process plants, pilot plants are usually characterized by a high density of operating equipment, so the risk to personnel is significant in the event of even a small fire or explosion. The equipments range from reactors to driers which have different hazard potential. In addition the gas cylinders are also used in some of the pilot plants and laboratories. The various heating devices like furnaces, ovens and electrical equipment are also used in the designated area. In case of any chemical leaks and subsequent fire/ explosions the cascading effects would be severe.

Untested processes and technology

Pilot plants often involve novel operations, whose nature and hazards are imperfectly known. For example an explosion occurred even after stopping the addition of chlorine to suspending iron powder during the manufacturing of ferric chloride in a solvent when the operator did not realize that reaction would continue if the agitator was on. Non availability of safety related information for some of the intermediates and the patented products could be a challenge for those who handle them particularly in case of emergencies.

Switching Operations

Lot plants frequently switch from one process operation to another, and sometimes the scale from one operation to the next differs by orders of magnitude, to a greater extent than is true for a full-scale plant. This may lead to contamination hazards or unsuitability of equipment for the respective process etc. A solvent was put into a small reactor to remove some polymer, which was stuck to the walls. Some monomer, which was trapped behind the polymer, reacted with the solvent, and the pressure rose. Bits of polymer plugged the relief valve, and the pressure broke a Glass connecting line.

Use of Non standard Equipment

The processes studied in pilot plants are typically still evolving and being modified. Similarly, the equipment, while admittedly small in size, is often home-made, one of a kind, and less tested and/or less robust than conventional process equipment. A non standard type vessel or reactor can cause problems with respect to safety. In one case height of the reactor only was increased to increase the volume and there was a run away reaction in the pilot plant because the designers did not understand that the surface area did not increase in proportion with volume and hence would not facilitate dissipation of heat generated during the reaction process.

Box item 2 : R & D Laboratory Fire

Fire occurred in R&D laboratory of a pharmaceutical intermediates manufacturing company. The laboratory was located close to the process area where many flammable solvents were stored and handled. The power supply to the A.C. units, lighting and other equipment in the laboratory was switched off from individual switches, keeping the supply on only from the main switch. Due to short-circuit in the electrical main-switch a fire started in the laboratory during non-working hours. After remaining unnoticed for quite sometime and spread quickly to the process section. Combustibles available in the laboratory and flammable solvents stored in the process area aided quick fire spread

Safety Management Program for Laboratories

Generally the research laboratories located with in the manufacturing premises are covered under the Factories Act and factories rules which addresses the general safety issues. However stand alone research laboratories do not fall under the above category and therefore the statutory compliance becomes non existent. With the increased number of accidents in bench scale laboratories the Bureau of Indian Standards (IS 4209) and Oil Industry Safety Directorate (OISD – GDN- 211) have brought out safety standards. The standards brought out by National Fire Protection Association, USA (NFPA 45) and Code of Practice issued by Royal Institute of Chemistry, UK are followed by international organizations worldwide.

Storage and handling of chemicals based on their hazards and chemical compatibility is essential in the laboratory units. The construction of work benches should take care of safety and ergonomic issues. Floor should be resistant to fire and chemicals and made anti- skid.

Provision of adequate number of fume cup boards and sinks to control the chemical environment with in the room. Dedicated storage for various types of chemicals and gas cylinders are recommended. The piped supply of gas from the cylinder manifold located outside the laboratory can minimize the fire and explosion hazard.

Frequent causes of bench fires are loss or under circulation, of condenser cooling water and contact between water and reactive metals like sodium. Such situations should be avoided in the laboratory.

Electrical safety is to be ensured by means of providing industrial type fittings and following the hazardous area classification while selecting the electrical appliances. Training needs to be imported to all concerned in the area of operation, maintenance and first aid.

NFPA classifies Laboratory units as Class A (High Fire Hazard), Class B (Moderate Fire Hazard), Class C (Low Fire Hazard), or Class D (Minimal Fire Hazard), according to the quantities of flammable and combustible liquids handled in the units. In case of high and moderate fire hazard units the construction should have the fire separation of 2 hours and 1 hour respectively. In addition to the above the standards suggest the fire prevention program consisting of ignition control like No smoking declaration, static hazards management, hot work permit, Good house keeping etc be followed with in the laboratory. Portable fire extinguishers are to be provided in such a way that the running distance does not exceed 15 m with atleast one extinguisher in each testing/ working room of the laboratory. The automatic fire detection system should be provided for early detection. Sprinkler system is recommended for laboratories by international standards.

Wherever explosion hazards are possible the construction should be explosion resistant with explosion venting facility.

A minimum of two emergency exits should be provided for each laboratory room. All exits should be clearly displayed and marked and the doors should be opening outwards.

The people working in the laboratories should exercise utmost care to prevent accidents. The generally suggested safety procedures are given in box item 3.

Box item 3 : HSE practices to be followed in Laboratories

a) Food and beverages are not permitted in the lab. Consume food and beverages only in properly designated areas. (Ontario Regulation 851 Section 131)

b) Use appropriate personal protective equipment at all times. (OHSA Section 28(1))

c) Use laboratory equipment for its designed purpose.

d) Confine long hair and loose clothing. (Ontario Regulation 851 Section 83)

e) Use a proper pipeting device. Absolutely no pipeting by mouth.

f) Avoid exposure to gases, vapours, aerosols and particulates by using a properly functioning laboratory fume-hood.

g) Wash hands upon completion of laboratory procedures and remove all protective equipment including gloves and lab coats.

h) Ensure that the laboratory supervisor is informed of any unsafe condition. (OHSA Section 28 (1)(d))

i) Know the location and correct use of all available safety equipment.

j) Determine potential hazards and appropriate safety precautions before beginning new operations and confirm that existing safety equipment is sufficient for this new procedure.

k) Avoid disturbing or distracting other workers while they are performing laboratory tasks.

l) Ensure visitors to the laboratory are equipped with appropriate safety equipment.

m) Be certain all hazardous agents are stored correctly and labelled correctly according to Workplace Hazardous Materials Information Systems (WHMIS) requirements. (Ontario Regulation 860)

n) Consult the material safety data sheet prior to using an unfamiliar chemical and follow the proper procedures when handling or manipulating all hazardous agents.

o) Follow proper waste disposal procedures.

When unattended operation of equipment with hazardous chemicals is warranted frequent visits by the trained security guard are required. Full instructions on the action to be taken in case of accidents and the details of person to be contacted in case of doubt should be available with the security guard assigned with the responsibility.

Lone operator guidelines should be developed where a single person is involved in the laboratory operation.

The laboratory should have a management system with suitable organization and competent people, systems and procedures, standards and codes of practice, and documentation. There should be a safety officer and safety committee, and safety audits should be periodically conducted.

Approach for Pilot Plant

The approach towards the safety of pilot plant can not be different from that of the full scale plant. However the uniqueness of challenge is associated with the understanding of the hazards pertaining to conversion of technology from laboratory scale to plot scale. The transfer of information from the chemist to the engineer should be regulated by formal procedures. The chemist should give a full description of the safety features of the process, including reaction kinetics and heats of reaction, limits of operating parameters and procedures and precautions adopted. The visualization of the engineer from the research reports to plant scale is the key challenge.

By virtue of the purpose of pilot plant there are inevitably some gaps in the design and process information when the plant is being designed. The recognition of various possible deviations and

related consequences is essential for the pilot plant owners and managers. The methods of hazard identification should aim to discover potential hazards rather than addressing the obvious hazards.

The key difference between the laboratory and pilot plant operation lies with the use of instrumentation. Considering the size and nature of closed systems the pilot plant needs to be fully instrumented not only to obtain design data and to ensure higher level of safety. The use of trips and interlocks and of fail safe valves which are common in full scale plant is relevant in pilot plants also. Recently the pilot plants handling hazardous chemicals have started using Safety Instrumented Systems wherever applicable.

Unlike full scale plants the pilot plants are housed inside the buildings. In case of chemical leaks the accumulation of vapor causes major problems. In addition to obvious problems like vapor cloud formation, pressure build up etc the asphyxiation and Short term exposure to toxic gases are also possible endangering people present in the plant.

Whenever there is a possibility of long term shut down of pilot plant and mothballing is required for an extended period the design of the equipment should take care of above possibility. Shutdown measures to take care of prevention of deterioration through cleaning and flushing of the plant. Similarly procedures for re-commissioning should also be developed.

The pilot plants can prepare a safety manual in line with the 'Pilot plant manual' brought out by AIChE. This document considered to be one of the pioneering guidelines for pilot plants deals with the issues pertaining to scale up, hazard identification, process design and design review, engineering standards for hazardous chemicals, radiation protection, maintenance and shut down procedures, operation at elevated pressures and temperatures etc.

Seven Strategy Concept

To ensure the high level of safety in the pilot plant the following factors have been identified to be crucial by some safety experts:

- Properly conducted pre construction safety reviews
- Leak tight design and construction
- Close attention to hazardous area classification for the electrical equipment
- Well designed ventilation
- Well planned storage
- Properly conducted maintenance
- Procedures for Control of Change

Pre Construction Safety Review

This review aims to ensure that any proposed design or modification is safe before a final commitment to carry it out is made. This review may often be preceded by other safety reviews (Preliminary Hazard Analysis) for relatively hazardous operations, but the preconstruction safety review remains the most comprehensive, detailed and critical review.

Properly conducted, it is a long and detailed exercise, which typically takes 4 to 12 hours to complete. To be effective, a preconstruction safety review should be conducted by an experienced group of trained individuals familiar with pilot plant design, equipment and operations, on a predetermined basis.

Leak tight Design and Construction

The design and construction of the equipment of pilot plant should be suitable for the various possible intended services and should be as per the standards. While designing the systems the possible deviations should be taken in to account. The suitable instrumentation should be thought of during vessel design stage itself.

Hazardous Area Classification

HAC should be done with the assistance of process experts as per the national and international standards. The inputs from the Consequence modeling can also be taken to make the judgement more objective.

Well designed Ventilation

In addition to the statutory requirements ventilation should be designed taking the wind velocity in the vicinity and the possible vapor generation during normal and abnormal conditions.

Well Planned storage

The main storage area and the day stores housing chemicals are to be segregated from the main pilot plant. Chemical leak control kit and absorbents for spillage collection should be available in the storage area.

Properly Conducted Maintenance

Preventive and Predictive maintenance schedules should be drawn up for all equipment and followed.

Procedures for control of change

Well drawn procedures for checking various safety parameters while changing the process, product etc can ensure safety in the pilot plant

Current Trends in Pilot Plant Safety

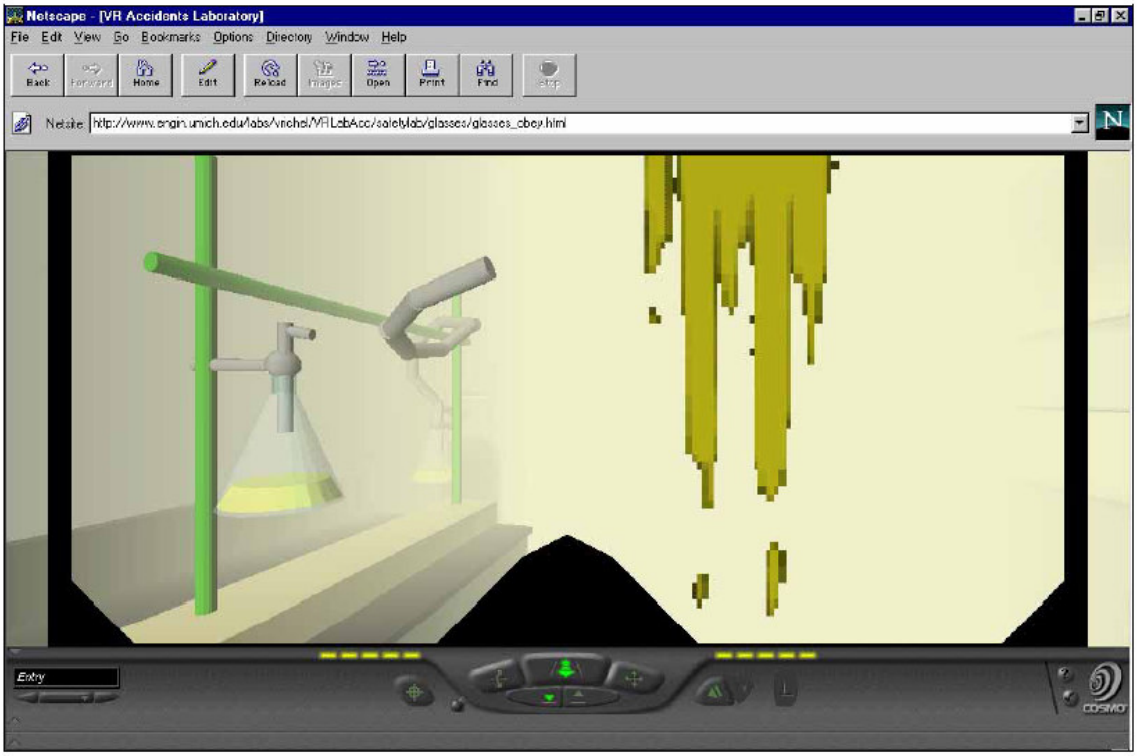
Recently a team of experts from American Institution of Chemical Engineers conducted a survey among the pilot plant operators of chemical process industry in USA and tried to understand the changes of safety experienced by them compared to the last decade. The following are the some of the changes highlighted:

- Formal safety reviews/PHA are carried out in the Pilot plant design
- Change Management – MOC is in place whenever new processes and products are handled
- Formal safety training is provided to all employees
- Increased use of automation/alarms/interlocks for pilot plant operations
- Catch tank is installed for the containment of run away reaction effluent
- Safety Relief Valve data base is instituted
- Formal thermo-chemistry review process is followed for each batch

The respondents also accepted that the increased statutory regulations and the social commitment are the drivers of the above change.

Software packages are available in the market to simulate the laboratory accidents with different safety levels and to visualize how the increased safety levels minimize the damage potential. (Refer box item no. 4)

Box item 4: Simulations showing how the safety glasses saved the user from the severe injury



With the increased thrust to research and development, innovation ,quality control development in each sector and outsourcing of technological development oriented activities to developing countries like India it is essential that similar facilities in India also adopt the above safety management control measures and improve the overall standard of safety. It is heartening to note that some of the multinational research laboratories and pilot plants located in India have already made headway in this regard and it is time for other installations to emulate them.

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About the author

J. Ramesh Babu is a chemical engineer with post graduation qualification in Business Administration. He holds the diploma in industrial safety. He is an Associate of Insurance Institute of India and Associate of Institute of Risk Management, UK. He has the experience of over 21 years in operations and risk management consultancy. He has conducted studies in the area of process safety, fire safety, insurance planning, risk and reliability for over seven hundred occupancies located in Asia (SAARC, Middle East, South East Asian countries) and Africa. He has conducted studies in dedicated and integrated pilot plants and research laboratories. He has carried out a number of major fire investigations on behalf of insurance companies. He has conducted three hundred training programmes on various topics of risk management. He has presented papers in seminars held in India, Sri Lanka Singapore, South Korea etc. His articles have appeared in leading technical and management journals like InfoRM UK, International Cement Review, UK, Pravartak, India and leading websites like Safety Users Group, USA etc. He is presently working as General Manager- Risk Services in Cholamandalam MS Risk Services Ltd., Chennai, India