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SAFETY IN DESIGN AND OPERATION OF IEL AMMONIA PLANTS 1/

by

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1.0 INTRODUCTION

The design, selection, application, operation and maintenance of machineries, vessels, pipework, electrical equipment, instrumentation and control systems of Indian Explosives Ltd's twin stream, 415 tes/day/stream ammonia plant had been and continue to be intensely influenced amongst other things by consideration of safety of plant as a whole and of people who operate and maintain it. The consideration of safety has been in fact a prime factor which took root and its rightful place at the conceptual stage of the plant and featured subsequently in detail design, construction and finally in operation. The consideration of safety found expression in almost all engineering disciplines in a variety yet compatible forms so that an acceptable level of safety was ensured in all areas of activities when the plant became available for production operation. The operational procedure was then formulated and practised incorporating the essential safety rules of the plant as conceived by the designers. To ensure that in course of normal operation of the plant, the safety requirements are rigorously met at all times and particularly so when there occurs a change of responsibility (e.g. handover from production to maintenance and vice-versa), elaborate Permit-to-Work/Permit-to-Enter and certificate of conditions and responsibility systems have been made imperatively essential prerequisites before a work on any part of the plant can commence. These systems are embodied in works and plant permanent instructions which have been issued to all line managers, to be followed by all concerned with operation and maintenance of the plant.

2.0 SAFETY APPROACH IN DESIGN

The detail design of IEL's ammonia plant has from its formative stage been governed by considerations of safety of plant and personnel. The concept of safety as applied to this plant has been a complex one and stemmed from recognition of hazards attendant to large volume, high temperature and pressure process employing highly volatile and inflammable petroleum feedstock (liquid naphtha) and producing toxic and inflammable constituent gases such as hydrogen, carbon monoxide, methane and ammonia. Apart from the obvious fire risk associated with the inflammable fluids, the plant designers and subsequently the operators and maintainers had to safe guard additionally against:

a) risk of explosion in reformer furnaces, pipelines and vessels in make gas and recycle streams and rotating machines particularly compressors.

b) risk of failure of protective devices when these are called upon to operate.

c) risks of mechanical and thermal failure of high energy content, large volume, pressure vessels and machines.

d) risk of exposure of plant personnel to electricity, high temperature process fluids, toxic agents and mechanical blasts.

e) involuntary and sudden loss of essential services (e.g. electricity, instrument air supply, inert gas etc.)

The risk of fire and explosion is by far the most dominant one being the likely consequence of failures of the types mentioned above. The design and operative approach and skill of the entire ammonia plant were therefore directed to achieve a long-term plant situation which would permit processing, handling and storage of flammable liquids, gases and vapours under such conditions of control that its liability to constitute a fire and explosion hazard was considered unlikely.

To achieve this task in practice, the designers set out to ensure among other things that:

i) all mechanical plant items and the interconnecting pipework, designed and manufactured and erected to exacting specifications possess requisite and proven mechanical and thermal capabilities to withstand normal operating conditions as well as credible abnormal but infrequent operating conditions in terms of stresses induced by pressure, temperature, flow, erosion, corrosion etc. with very low long-term probability of mechanical failures.

ii) the interconnected piping systems are of welded construction with least number of efficient and mechanically robust joints so that probability of leakage of flammable gases, vapours and liquids is minimal.

iii) the process control is sufficiently automated by suitably designed and selected instrumentation system having a high level of reliability, accuracy, repeatability and speed of response.

iv) the important process variables are adequately and continuously monitored and are equipped with reliable alarm and trip systems to demand operative actions in good time and to render the plant item(s) or section(s) safe automatically should the abnormalities attain dangerous magnitudes.

v) the equipment and vessels operating under high pressures and/or temperatures are provided with reliable mechanical protective devices (e.g. relief valves, bursting discs etc.) as second line of defence to instrumented trip system.

vi) the vented gases and vapours are released away from possible sources of ignition.

vii) in the event of involuntary and sudden loss of essential utility services (e.g. power failure) the plant is shutdown in a controlled sequence to a safe condition with minimum discreet and predetermined operative actions.

Having reduced the probability of accidental exposure of inflammable fluids down to a practicable minimum, the designers turned their attention towards survey of potential sources of iginition within the ammonia plant with a view to eliminate or contain them.

It could readily be conceived that if such potential sources of ignition could be eliminated or rendered harmless under normal operating conditions by suitable design, then probability of their becoming source of danger at any point in time would be low. Since the designers have already ensured low probability of accidental exposure of flammable fluids, the combined probability of a fire or explosion arising out of exposure of flammable fluids to an already existing source of ignition would indeed be very low. This is one of the key features which operational safety of IEL's ammonia plant is based on and, therefore, maintenance of this feature at all times becomes an important function of production operation and maintenance departments.

3.0 ELECTRICAL CLASSIFICATION OF HAZARDOUS AREAS

IEL's fertilizer plant at Kanpur is power intensive. The factory maximum demand is 44 MW and characteristic consumption is around 750 kWHrs/Te of urea on a site basis. There are a total of 550 electric motors used as prime movers in the factory of which 123 are installed in the ammonia plant. These motors and numerous other electrical equipment such as light fittings, PB control stations switches etc. in their normal and conventional industrial form would be potential sources of ignition because electrical energy required to ignite a most incendive mixture of hydrogen/air or methane/air escaping at a pressure and elevated temperature is very small, being a few millijoules.

In order to arrive at the required specification of these electrical equipment which would prevent these from being potential sources of ignition, the entire ammonia plant was subject to an area classification in accordance with B.S.C.P 1003, ICI Engineering Codes and Regulations Group C, Volume 1.3 and Electrical Safety Code of the Institute of Petroleum, UK.

The geography of classified areas of the ammonia and other plants of IEL's fertilizer factory is shown in drawing No.IF/Z 168075.

Most of the areas in ammonia plant came under Division 2. Isolated sections like PSR and Reformer Feed Pump area and top of reformer furnace at 42' - 0" level came under Division 1 classification. Division 1 and 2 areas are defined as follows:

Division 1 - An area within which any flammable or explosive substance whether gas, vapour or volatile liquid is processed, handled or stored and where during normal operations and explosive or ignitable concentration is likely to occur in sufficient quantity to produce a hazard.

Division 2 - An area within which any flammable or explosive substance whether gas, vapour or volatile liquid although processed and stored, is so well under conditions of control that production (or release) of explosives or ignitable concentration in sufficient quantity to constitute a hazard is likely only under abnormal conditions.

4.0 SAFETY IN DESIGN AND APPLICATION OF ELECTRICAL PLANTS

The design and application of electrical equipment in the ammonia plant for the classified areas were subsequently based on ICI Engineering Codes and Regulations and BS 4137/1967 entitled 'Guide to the Selection of Electrical Equipment for Use in Division 2 Areas'. Some of the essential features possessed by electrical plant items to become suitable for use in Division 2 areas in IEL's ammonia plant were as follows:

Either a) Basically totally enclosed, non-sparking apparatus (e.g. squirrel cage induction motor)

Or b) where risk of sparking under normal operations could not be avoided, the apparatus was designed as 'enclosed sparking' (e.g. microswitch, mercury switches, special lamp holders for light fittings, sparking contacts submerged in non-flammable oil) so as to preclude exposure of flammable gases and vapours in sufficient quantity.

Or c) flameproof apparatus (BS 229)

Or d) intrinsically safe apparatus (BS 1259)

Or e) pressurised with clean air or inert gas with alarm facility.

Some specific examples will serve to illustrate the safety features incorporated in design of electrical plants.

1. Totally enclosed closed air circuit large (4200 KW) low speed (330 rpm) synchronous motors driving synthesis gas compressors have brushless (and hence non-sparking) excitation employing solid state switching circuits and rotation rectifier bridge. This was a departure from conventional design to make these machines suitable for Division 2 areas.

2. 420 kW transformer/transductor unit feeding ammonia converter start-up heaters is all filled and contractless by design again making the equipment totally enclosed and non-sparking. This too was a departure from conventional design where voltage regulating section normally employs tappings and moving contacts.

3. Motor control panels in the compression building containing contactors, relays etc., (i.e. sparking devices) are purged with compressed air to keep the panels at a positive pressure above the surrounding atmosphere and thereby denying entry of flammable gases and vapours.

4. All motors other than the synthesis gas compressor motors are squirrel cage induction type designed to increase safety specifications to ensure low probability of electrical and mechanical failures with operating surface temperature of stator casing very much below the ignition temperature of any conceivable gas mixture likely to be encountered during a plant breakdown/abnormality.

5. As many of the motor faults take place in terminal chambers, this has been safe-guarded against in large 415V and all 3.3kV machines by either adopting a phase-segregated, fibre glass lined terminal box design or by employing epoxide resin moulded BEMA terminal boxes.

6. Plant switchroom which housed the normal industrial switchgear is pressurised with clean air with audio-visual alarm upon failure of pressurising air.

In Division 1 areas only certified flameproof equipment has been used.

Apart from the above safety features in design of electrical equipment, the plant distribution system is equipped with 'automatic start-on-mains-failure', diesel generating set which starts up within 20 seconds of a complete power failure or major system disturbance and provides power to essential drives, lighting system, communication, alarm and trip systems and electronic instrumentation necessary to maintain safe conditions in the shutdown plant.

Power sources of plant alarm and trip systems are backed up by liberally rated heavy duty and high capacity lead-acid storage batteries floating across the constant voltage rectifier cubicles to ensure that at no time are in alarm or trip systems devoid of electricity supply.

To protect personnel from hazards of static electricity and to prevent ignition of flammable gases and vapours by electrostatic discharge all vessels, discharge and transfer points of flammable fluids are earthed by PVC sheated aluminium conductors to an interconnected system of earth electrodes whose combined resistance to earth during the dryest months does not exceed one ohm.

Intrinsically safe and certified insulation and continuity testers are used in Division 1 and 2 areas during electrical maintenance. Where such special apparatus is not available for carrying out other electrical testings, gas samples in the immediate vicinity of the plant item is tested by an explosimeter and electrical work is undertaken only when conditions are safe.

5.0 INSTRUMENTED SAFETY

The ammonia plant of IEL is of necessity highly automated. The instrumentation of main process stream not only provides for measurement and control of all important process variables (e.g. pressure, temperature, flow level, composition) backed up by a suitably designed audio-visual and discriminative alarm system but also caters for a number of vital protective functions through fast acting high integrity trips. It is through these instrumented protective trips that operational safety of the plant has largely been achieved. The safety instrumentation and trip system have been designed to perform the following important functions.

a) To prevent formation of explosive conditions of flammable fluids inside process equipment.

b) To protect expensive reaction catalysts from damage or deactivation.

c) To protect machines, pressure vessels and piping from over-pressure, over-temperature and other damaging abnormalities (e.g. loss of lubrication of bearings, excessive vibration, axial displacement of shafts etc.)

d) To protect operating personnel from injury due to catastrophic failure of process plant items.

The safety instrumentation has been applied in various forms and in varying concentration in all sections of the ammonia plant namely:

i) PSR Section;
ii) Gasification Section;
iii) Purification Section;
iv) Compression and Synthesis section including refrigeration;
v) Ammonia Recovery Section;
and vi) Ammonia Storage Section;

The gasification section has by far the highest concentration of protective trips in the whole of ammonia plant. Most of the trips of this section have been designed to prevent explosion of gas/vapour mixtures inside process equipment. The protective trips of purification section have been employed mostly to protect reaction catalysts in various vessels from damage along with a few trips of other protective functions. The trips of compression, synthesis and refrigeration section are directed primarily towards protection of machines. In ammonia storage trips have been designed and applied for protection of machines and prevention of implosion. Protective trips in other sections are relatively few in number.

A few examples of process trips in actual use in IEL's ammonia plant would serve to illustrate the application of instrumented safety in design and operation.

5.1 GASIFICATION SECTION

There are a total of 26 credible fault conditions envisaged which when occur will activate upto 13 process trips and 2 start-up sequences. A fault condition will activate upto 7 process trips/start-up sequence depending on the nature of fault. Similarly a process trip will be activated by upto 8 independent fault conditions.

5.1.1 REFORMER FURNACE EXTRA HIGH PRESSURE

Primary Reformer furnace has been so designed that it is essential at all times to maintain a negative pressure inside the furnace. Development of condition leading to even very small positive pressure (few inches w.g.) can cause hot flue gas and flame to emerge through peepholes which in turn cannot only seriously injure operating personnel but is also capable of initiating a fire or explosion of external flammable gas/vapour mixture. The safety instrumentation detects development of higher than normal pressure inside the furnace and above a set value trips shut fuel gas and fuel naphtha supplier to the furnace through the respective solenoid valves and renders the furnace safe. Failure of reformer I.D Fan would lead to identical pressure condition and would activate same spectrum of fuel trips.

5.1.2 STEAM - MIXED VAPOUR EXTRA LOW RATIO

The catalyst in primary reformer is exposed to degradation and damage if the steam/carbon ratio falls to 2.8 or below. When the ratio drops to this level process trips are actuated to shut off mixed vapour flow to primary reformer and process air to secondary reformer, ensuring protection of reformer catalyst.

5.1.3 EXTRA LOW FLOW OF PROCESS AIR TO SECONDARY REFORMER

About 18,000 - 20,000 RM^3/hr process air is normally supplied to secondary reformer by centrifugal air compressor with a delivery pressure of 31.5 kg/cm^2. The air is fed against a constant back pressure in the reformer with a p.d. of about 1 KC^2 across the flow control valve.

In the event of drop in compressor delivery, p.d. across the control valve decreases rapidly and so does the air flow to the secondary reformer. Below 4,500 RM^3/hr flow level, the p.d. across the C V tends to disappear altogether causing instantaneous stoppage of air flow to the reformer with a distinct tendency to develop a backflow into P A line with risk of catastrophic explosion of air/flammable gas mixture. The safety instrumentation initiates a trip below 4,500 RM^3/hr which isolates the P A line completely thereby preventing the backflow and consequent risk of explosion.

5.2 PURIFICATION

There are six credible fault conditions which will activate upto seven process trips.

5.2.1 METHANATOR HIGH TEMPERATURE TRIP

As the methanator is capable of converting residual CO_2 to CH_4 in small quantities, any break-through of CO_2 upstream of methanator can lead to violent and highly exothermic reaction with excess CO_2 which if left uncontrolled can cause thermal failure of methanator. To prevent such a situation, a high temperature sensor monitoring the highest catalyst bed temperature has been employed to trigger off a process trip shutting off gas stream inlet to methanator and simultaneously tripping out the related synthesis gas compressors. These compressors if left running would create a vacuum on the suction side with possible failure of joint, air ingress and resulting fire and explosion.

To back up the automatic trip of the compressors, manually operable switches have been provided in the plant control room to trip the compressors manually and to trip the section of main 11 kV switchboard as second and third lines of defence.

6.0 RELIABILITY OF PROTECTIVE DEVICES

The most essential feature of protective device is that it must not fail to operate whenever called upon to do so, in most of the occasions and in the infrequent events when it does fail, it must fail to safety.

The design of instrumented safety systems of IEL's ammonia plant has therefore been governed invariably by criteria of reliability of components and systems as a whole. This has entailed critical examination and evaluation of each and every component forming parts of trip system and as a result a high integrity and reliable trip system has emerged. Trips have been catagorized for specific protective functions basically in three reliability groups having ceilings of fractional dead time ranging from 4 hr/yr to 5 weeks/yr. Experience abroad as well as in Kanpur ammonia plant has shown that these reliability indices have generally provided the required protection security of plant and personnel.

In operational field these indices have been used as basis of programmed trip testing of protective devices so that the designed reliability standards are maintained at all times.

7.0 OPERATIONAL EXPERIENCE

Operational experience during the last six years has shown that although most of the safety devices incorporated in design of IEL's ammonia plant have performed in accordance with designers' expectation, there had been a few problems such as the ones illustrated below:

a) Use of electrolytic aluminium conductors instead of conventional copper in cabling of electrical plants in Division 1 and 2 areas has from time to time led to problems of sustained overheating (a potential source of ignition which was not considered serious at design stage) and failures at the terminal chambers. The consequence of thermal failures in Division 1 areas was further aggravated by 'Thermit' action which permits hot molten aluminium to propagate outside a protective chamber. Many of the failures were due to gradual oxide formation whilst the others were due to fatigue induced by continuous structural vibration, particularly in compression buildings and synthesis section. Mechanically/hydraulically crimped joints with oxide inhibitor grease have reduced the magnitude of the problem substantially except those in vibration intensive area.

b) Flameproof enclosures of large 415 V electric motors were found inadequate to withstand electrical fault forces and to prevent products of internal short circuit from coming outside the enclosure. Fault capacity and phase segregation criteria should be used in future designs.

c) Rolling bearing housings of 3,000 rpm motors tend to operate at dangerously high surface temperatures (a potential source of ignition) during summer months, due to inadequate cooling and thermal capacity of bearing cartridges. Future designs should improve upon cooling and provide sufficiently large housing to act as effective heat sink.

d) Naphtha discharge drum in reformer feed pump area had no high level alarm. As a result there was a risk of the vessel overfilling, spillover running into flare stack, and causing fire hazard. A high level alarm was installed to prevent this from happening.

e) Anti-surge control of process air compressor by a special flow/pressure controller (Foxboro Yozall) was found unsatisfactory during commissioning. Blow off control valves were modified to secure a stable operating point away from the surge curve.

Further modification is being designed to improve anti-surge protection.

f) The let down control scheme of hydraulic turbine, letting down Benfield solution from absorber to regenerator tower did not function efficiently exposing the turbine to destructive overspeed and risk of disintegration. Protective system was suitably modified to establish reliable and safe operation of the machine.

g) Nitrogen generators of the inert gas plant had unsatisfactory residual hydrogen control. This gave rise to an explosion hazard as well as a risk of damage to catalysts which are often blanketted by nitrogen from inert gas plant. The instrumentation system was successfully modified at site to contain the residual hydrogen within specification limit and the problem was thus eliminated.

h) Failures of aluminium gasketted double cone joints of HP vessel closures had been rather high. One such recent failure let to a fire in ammonia synthesis section. Various measures are currently being considered to minimise failures and to prevent a fire from breaking out.

8.0 CONCLUSION

The success of operational safety of an ammonia plant like that of IEL seems to be heavily dependent upon operating and maintaining the process stream with explicit knowledge of designers' philosophy and vision, stringer procedural disciplines and constant review and resolution of those problems which tend to invalidate the conditions of safety.

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