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FIRE AND EXPLOSION PREVENTION IN COMPRESSED AIR PLANTS

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Safety is one of the main assets of pneumatic tools and equipment. Unfortunately we cannot claim the same advantage for compressed air plants, since fires and/or explosions in compressed air systems occur all over the world. Fires and/or explosions endanger the health and lives of the personnel being in the proximity of the delivery systems of compressed air plants such as piping, air receivers, pulsation dampers, aftercoolers etc. There are sometimes heavy financial losses when compressed air plants are damaged but there are occasions when more serious losses occur to stoppage of production which is dependent upon the delivery of the compressed air.

The author of this paper had the opportunity to study the causes of several explosions in a railway truck factory in a compressed air system operating at a pressure of 7 atm/100 psig/. In one case the autoignition of degraded oil accumulated in the bend of the discharge piping caused such a heating of the tube that the steel became plastic. The wall of the tube had blown up followed by the bursting of the tube. The escaping compressed air threw two steel work benches from the proximity of the discharge system several tens of metre away and the accumulated burning oil was thrown onto the wall of a building at a distance of about 200 m. The effect of it was similar to that of a napalm bomb. It is interesting to note, that the accidents always arise either in the period preceded by a substantially reduced loading of the plant or during the reduced consumption of compressed air. The inspections of the piping after the accidents have shown considerable amount of carbon deposits and of the thickened oil.

The compressed air plant in the railway truck factory was equipped with three two-stage reciprocating compressors each having the capacity 3650 m$^3$/h$^{2100}$ cfm, and by a turbocompressor 6300 m$^3$/h$^{3700}$ cfm/. The compressor oil used for lubrication of the reciprocating compressors had been manufactured from inappropriate paraffinic crude oil. But tests of the fresh oil, regenerated oil and of samples taken from the discharge system showed satisfactory results. The flash point of the oil was much higher than the air discharge temperature of about 150$^{°}$C at least 226$^{°}$C/465$^{°}$F/ and there was no explosion at the Kretz test at the pressure 7 atm/100 psig/ using glowing coil for initiation. At the time of accidents there were no faults with the reciprocating compressors and according to records of operators, the compressors have continually worked with normal discharge temperatures. All of the accidents happened in the cold seasons in December, January, March and September/.

The rate of oil was at the critical time 500 g/h per compressor instead of 400 g/h as recommended by the manufacturer of the compressors due to a slight seizure of the differential pistons.
After the mentioned disaster the search how to avoid dangerous situations was done and the solution was found in the change of oil for one with a higher flash point. But as we shall learn later it is not the final solution, since it means that even greater difficulties may occur later due to the increased oil deposits in the piping.

The compressed air in this particular case was used primarily to feed pneumatic forge hammers/ about 2/3 of the air consumption/ and in order to reduce the compressed air consumption the discharge piping had been thermally insulated. This was the only deviation from the current outlay of compressed air plants. Apart from this only one point the case is a typical example of situations where fires and explosions in compressed air plants arise. It will be further analyzed, in order to make conclusions from the findings of fire and explosions causes and to avoid these dangerous situations.

CAUSES OF FIRES AND EXPLOSIONS IN DISCHARGE PIPING.

There are many records of fires and explosions in discharge piping of air compressors in many countries like U.S.A. Great Britain, Germany and Czechoslovakia as well.

Oil or its deposits could be very dangerous when incomplete burning in cylinders or discharge piping of compressors occurs. This gives rise to carbon monoxide, which can be also present in the air polluted by exhaust gas from internal combustion engines operating in the proximity of the compressor suction line. The carbon monoxide escaping with the air from pneumatic tools is very poisonous to plant workers in closed conditions. The careful analysis of circumstances favourable to the rise of fires and explosions has proved these causes to be in discrepancy with the up to date suppositions and seen at first to be paradoxical.

The first presumption how to prevent fires and explosions in the discharge piping, is careful oil section. Oil should have the lowest permissible viscosity, in order to make the evaporation of the oil in contact with hot piping walls easy, for the purpose of being carried by the compressed air into cooler parts of the piping and into air receiver. The oil breakdown and the carbon deposits, which are very hazardous from the point of view of fire prevention, will be avoided. The heavy carbon deposits due to their insulating effect make possible local overheating and inflammation. Besides the high temperature the high air pressure contributes radically to the rapid oxidation of oil. The influence of the air pressure on the chemical activity of oil for oxygen can be deduced from the fact that however the air temperatures behind the first compressing stage are identical or even higher than that of the discharged air there are no fires or explosions in the interstage piping.

Operation tests of the Atlas Copco Company with their compressors along with the laboratory tests of the Shell Intl./ 1/ have proved that paraffinic oils tend to deposit more coke on the piping wall than more volatile naphthenic oil and that the preference should be given to a straight distillate before a blend of two oils of different viscosity in order to get the desired viscosity. There are records of explosions not only in the discharge piping but even in the aftercooler which was considered before as the best protection against explosions and fires.

The above mentioned tests on the applied oil have apparently shown that the oil was not the cause of explosions, but comparing the test conditions with those in the discharge piping such differences were found that the conclusive evidence of the tests was refuted. The flash point of the oil had been determined at atmospheric pressure while the pressure in the piping was 7 atg which lowers considerably the flash point. But even more important is the fact that the oil was in the form of a mist, which can substantially reduce the flash point.
of oil. Stoichiometric ratio in such a mist are quite different from the ratio in the Kretz apparatus even if the used pressure was 7 atg.

According to the statement of Mr. F.I. Fowle /3/ the spontaneous inflammation of carbon deposits in the piping, sound dampers and aftercoolers was found to be result of the exothermic oxidation. The heat generation by oxidation was increased exponentially with the temperature while the heat at transfer was proportional only to the temperature. The carbon deposits in the piping can grow to a certain amount, when the heat removed from the surface is no more equivalent to the heat generated by the oxidation. The inflammation sets in at a certain critical air temperature whose value will vary considerably, namely from 70°C to 300°C.

Besides the oil quality the operating mode has a great influence on conditions promoting fires. In the UK it was found/1/ that compressors running at intervals with no load at present more severe conditions in comparison with those running continuously on full load. The fully loaded continuously compressors remain without deposits even when using oil prone to deposit formation, while similar compressors running intermittently with no load using very good oils tend to form deposits.

Interesting is the statement of J. Munck/2/ that big compressors are more prone to deposit formation although their efficiency is better and the discharge temperature lower than those of small compressors. The lower temperatures are inconvenient: since the oil evaporation takes a long time and being degraded by oxidation the oil forms solid deposits. This observation was confirmed by explosions in the mentioned railway truck factory because the explosion occurred always during the cold season.

In accordance with observation of the Shell Centre Mr. J. Munck has found too, that the fire risk was increased in cases of the substantially reduced air flow through the piping. Since the carbon deposits are not cooled by the flow of air their temperature may rise above the autoignition temperature. This observation is in full agreement with the facts found out in the railway truck factory since there also the explosions or fires came just at the time of the reduced loading of the compressed air plant. The lubrication of the compressors being independent of the compressor loading, the machines are overlubricated when on reduced load. At the same time oil is not carried into the discharge piping during the period of no load. The oil covering the carbon deposits flows off and so after restoration of the air delivery, the air necessary for the burning of the oil deposits has a free access and the autoignition then starts. This statement appeared to be confirmed by explosion in the piping of a high pressure air compressor in a chemical plant in Czechoslovakia. These explosions always arose after the compressor had been shut down for several days.

THE MEANS TO AVOID FIRE AND EXPLOSION RISK

Some means how to avoid fire and explosion hazards or to reduce drastically their occurrence follows from the analysis of their causes:

1. Selection of an appropriate oil is primary importance.

2. Overlubrication of compressors must be avoided. It can result in worse consequences than underlubrication. Double acting reciprocating compressors are much better than the single-acting ones as far as the oil consumption is concerned.

3. The oil consumption can radically reduced by using the Teflon piston rings similar to the service life of cast iron rings operating with abundant lubrication and is several times longer than the service life of Teflon rings of oil-free compressors.
4. Switching from hydrocarbon mineral oil to a synthetic oil as a cylinder lubricant may very much improve the safety of the compressed air plant. Such synthetic oil based mostly on tri-cresyl phosphate (e.g., Hydraulic Ac of Monsanto or on Fluorosilicone) (e.g., Dow Corning Corp.) can drastically cut maintenance costs or compressor teardown. However some of them may bring additional problems such as not being safe with all materials used in compressor manufacturing or having not the capability of corrosion prevention like hydrocarbon oils and sometimes the problem of the high cost will arise.

5. Some experts recommend the removal of carbon deposits and oil from the discharge system at least every six months (5). This method aims to prevent the formation of such a thick layer that could promote the autoignition of the carbon deposits. We must agree that such a method is time consuming, laborious and expensive.

6. Mr. Punke/Linde A./5,p.58/ affirms that it is difficult to separate oil vapours from a dry gas, but the injection of steam makes the separation very easy. The usual air pressure 7 atg is corresponding to the saturated steam temperature ca 170°C/340°F/, which is not far from the compressed air temperature. This means that the steam injection into the discharge piping near the compressor and following oil separation will keep the other part of the discharge steam free of oil and carbon deposits. The excessive humidity may be sometimes prejudicial to this mode of fire prevention.

7. The injection of water instead of steam was recommended by Mr. H.Q.Duguid (7). There is a closed circuit of water circulation. The water is injected in the compressed air by a spray nozzle in the delivery branch of the compressor and passes with the air through the aftercooler to be separated in the following separator. The separated water is recycled by a pump whose head is set by the spray nozzle operating pressure.

8. Mr. W. Jasenitz (6) reported of a specially designed electrostatic filter to remove oil from the hot compressed air, operating with the efficiency of 88.4 to 91.9 percent.

9. Nonexpensive mode of fire and explosion prevention both from the primary cost and operational cost is the cooling of air in the aftercooler. It is necessary to avoid the aftercoolers of conventional type, since these may be themselves potential sources of fire or explosion hazard according to past experiences /2,3/.

Applying the aftercooler in the proximity of the delivery branch of a compressor is advantageous, in spite of the apparently increased compressed air consumption due to the reduced air temperature and hence the increased weight of the air feeding the pneumatic tools and/or equipment.

On the other hand placing and oil and water separator immediately behind the aftercooler makes the use of other separators in the piping dispensable. No loops or expansion compensators in the piping are necessary and in this way the pressure drop of the piping will be reduced (8). The cooling of the air and separation of the air humidity close to the compressor prevents or at least drastically reduces the condensation of the air humidity in the piping and the carrying over of the condensate into the pneumatic tools and machinery. By washing off the oil film it can cause corrosion and rapid wear by a substantially increased compressed air consumption.

The expedient water removal cuts radically the maintenance costs of the pneumatic tools and
prevents the pipes bursting due to ice formation during frosty weather. From the point of view of power economy it is important that the leakages may bring about considerable losses of compressed air. A great asset of the compressed air cooling is the increased accumulation capacity of the discharge system thereby reducing the number of interventions of the compressor capacity control.

10. A very convenient aftercooler type was developed for this purpose by the author of this paper. Unlike the conventional type of aftercoolers there is no danger of autoignition of oil deposits in the cooler. Besides being an excellent cooler with the overall heat transfer coefficient as high as 300-540 kcal/hr²°C/60 - 110 Btu/sf hr°C², it is at the same time a very efficient filter removing all liquid and solid particles/also of submicron size/with efficiency at least 99.5 per cent, assuring clean piping and 100% safety of the whole discharge system, when placed close to the compressor.

The principle of this surface froth gas cooler is shown in the Fig. 1. The hot compressed air is entering through the branch 1, ascends through the holes of the perforated plate 2 and together with circulating water/or other suitable liquid/brought to the plate through opening 3 forms froth on the upper side of the plate 2, which it carries away to tube bundle 4. There is very intensive heat transfer in the turbulent froth, from the froth to the wall of the tube bundle and from the tubes to the cooling water entering the shell 7 of the cooler through the branch 8. The coefficient of heat transfer is in the range of the one of liquid to liquid heat exchangers. The cooling water being directed by several baffles 9 across the tube bundle leaves the cooler through the branch 10. The froth, after passing the tubes of the bundle, flows into the separator 5 where the circulating water forming the froth with the air is separated from the air taking simultaneously all of the oil and any impurities carried out of the compressor. The cool saturated air comes out from the heat exchanger through the branch 6. The separated water after settling in the receiver II is automatically recycled through tube 12 and control valve 13 to the perforated plate 2.

This surface heat exchanger has the asset, that the heat transfer surface on the air side is continually cleaned by the froth and that only a little amount of water or other liquid, which is only a means to increase the heat transfer coefficient and to extract impurities from the air, is in contact with air. So unlike other froth coolers the cooling water cannot be polluted by oil carried by the air and there is no need to pump the water against the head which is given by the air pressure. The oil
caught above the water level in the receiver may be intermittently or continually drained off.

The cooler together with the separator built-in or placed above the cooler extracts effectively all the oil from the compressed air. Even with strict requirements on the air purity there is no need to use expensive and less efficient oil-free compressors.

Because of the very small dimensions of this type of cooler and bare tubes used, the surface froth gas cooler is much less expensive than the most parts of conventional coolers.

The invention of this surface froth gas cooler is protected by Czechoslovak, French, U.K. and Japanese patents/with some other patents pending/and has proved to be very successful in operation not only in Czechoslovakia where e.g. an intercooler of a hydrogen mixture compressor with the capacity of 9500 cfm has run for more than two years in continuous operation, but also in other countries such as Japan and West Germany.

The pressure drop of the new exchanger does not exceed the usual values of conventional heat exchangers.

The air coming out from the separator of the cooler is just saturated similar to the air coming from the separator placed behind a conventional aftercooler.

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