SAFETY FEATURES OF REFRIGERATION SYSTEMS FOR ATMOSPHERIC STORAGE OF AMMONIA

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Introduction (D. E. Eddy)

Last year my associates and I attended the A.I.Ch.E. Air and Ammonia Plant Safety Symposium in Las Vegas for the first time. We were so impressed with your problems, such as 15,000 ton roll-overs, and your serious approach to these problems that we offered to participate in this program. Basically, we will discuss general safety practices that we apply in our refrigeration systems and then we will certainly attempt to answer any specific problems you may have.

Last year at this time, many of you were in your first design, construction, or operating situation for ammonia storage. As you all know, anhydrous ammonia production is expanding at an annual rate of 11% in the United States. In the future many of you will be involved in overseas operations where the production is far behind the United States.

To date we have designed and installed many of these systems and it is surprising that each one of them is custom built. We can think of very little duplication in this type of plant. The expenditures for stand-by capacity and safety features vary with the location and the cost of product arriving at the terminal, the price of the product leaving the terminal and your final concept of design at the end of a long study of these various aspects. I would like to point out that the figures we will show are of a typical plant, and we prefer to withhold the name at this time.

We have seen stand-by safety features designed into the plant, from the minimum to the maximum, and we would like to point out the designs from the numerous offerings that we feel should be in the facility. Mr. Schroedter will discuss typical flow diagrams and safety features and then Mr. Strauch will disclose the feature of a particular operation. We will then be open for your questions.

Technical aspects (P. M. Schroedter)

The design condition for a low temperature ammonia storage refrigeration system is based on the construction of the storage tank. The tank is not a pressure vessel and the operating range is between 2 in. or 3 in. up to 10 in. of water. The size of the refrigeration system is based on the holding load plus the filling load.

Every refrigeration system should have stand-by capacity. This means there should always be a compressor available in case the main compressor becomes inoperative.

To stay within operating range, the compressors would have to be equipped with capacity controls. In extreme cases, it was found necessary to unload these compressors completely to almost zero percent load which requires balance loaders by creating artificial load and keeping the compressors continuously on the line.

It is the general practice that all controls with spark producing contacts be enclosed in NEMA 7, or in explosion-proof cases. This is in the immediate neighborhood of the tank. If the controls are placed some distance away from the tank, NEMA 4 weather-proof controls can be used, or if they have a building, NEMA 1 controls can be employed.

Standard safety equipment

As standard safety equipment for each compressor, we would recommend a high pressure cutout, a low pressure cutout and an intermediate pressure cutout. Each compressor should also be protected by an oil pressure failure switch and, if exposed to low ambient temperatures, a crankcase oil heater.

In regard to protection of this refrigeration system, we want to stress that these compressors are gas compressors and they will be damaged if liquid enters from the suction line. We know from experience that even the largest tanks will have some liquid slop-over in the suction line, even if the suction gas is taken out of the center of the tank right underneath the roof. We know there can be a certain layer of fog and mist above the liquid. This ammonia fog can be sucked into the line and could cause damage to the compressor. For this reason, we emphasize that each ammonia compressor should be protected by an accumulator to catch this slop-over.

Flow diagrams

To illustrate the application of these safety devices, we will use several flow diagrams.

On the flow diagram, shown in Figure 1, we see on top of the tank the pressure differential cell. This

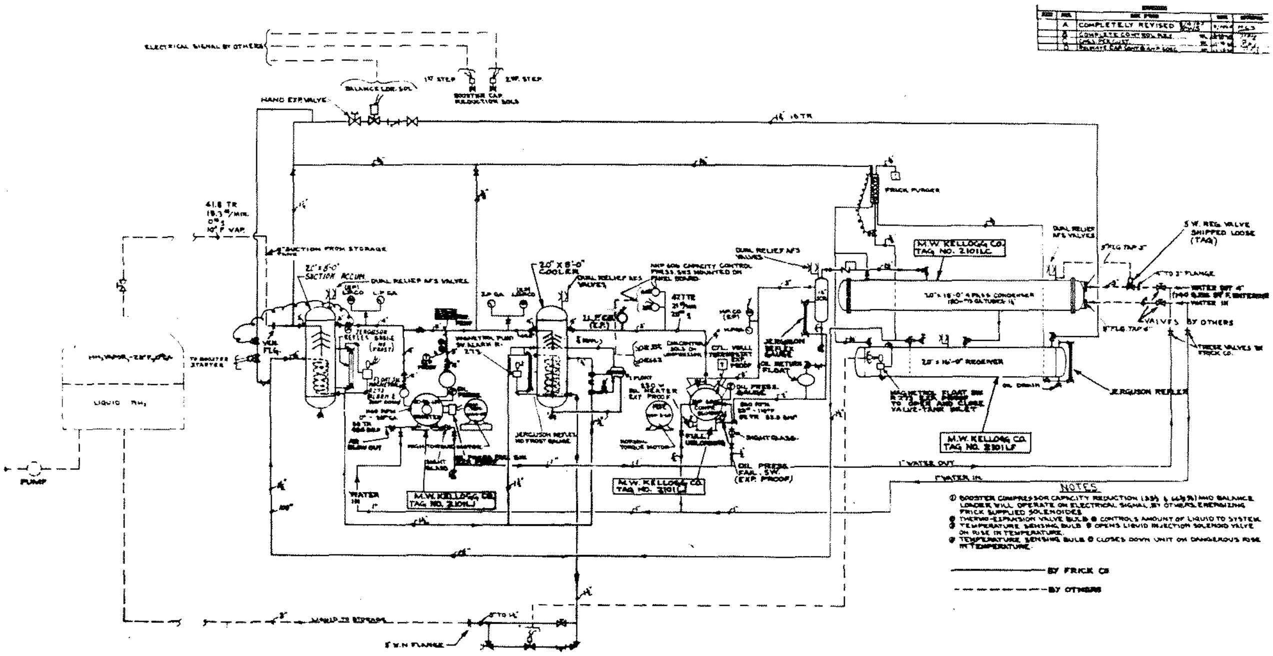


Figure 1. Flow diagram for low temperature atmospheric ammonia storage (package unit).

cell senses the pressure within the tank and controls the amount of refrigeration required. Here you see the suction accumulator which protects the compressor from liquid slop-over. A float switch can be mounted at the high level mark which will sound an alarm or shut down the equipment. You will also see that each compressor is protected by a high pressure cutout, and a low pressure cutout, also each compressor has a built-in safety relief valve. Here you see the oil pressure failure switch and a crankcase oil heater. The gas and liquid cooler which is installed between the booster compressor and high stage compressor has two jobs to fulfill. It has to subcool the discharge gas of the compressors down to saturation and subcool the hot liquid to the intermediate saturation temperature. Again, you will find a float switch which protects against too much liquid. You will also see that each vessel is equipped with a safety valve. This holds true for the condenser, on the right, which is also equipped with a relief valve.

In Figure 2 every vessel is protected by a dual safety valve. We recommend the dual safety valve. On this flow diagram you again see the accumulator which protects the compressor from slop-over. Here the accumulated liquid gathers in the receiver below and then is pushed back into the intercooler by manual operation. This intercooler has two safety features. You will see the high level alarm and the high level shutdown.

Each tank has its own full stand-by capacity. That means the engine room has a total of 8 compressors, two boosters for each tank and two high-stage machines.

Double control system

A very interesting point is the double control system in the main engine room. The engine room houses the gauges and the main cutouts. In addition, it contains a control board where all the other remaining pressure switches are installed. This control board can be set up in the engineer's office where he can immediately set different pressures and have complete control over the entire system at any time. All vessels are protected by the dual safety valve.

One should note that the cold liquid comes from the tanks and goes past the engine room into the ammonia heater which heats the -28° liquid up to 40° or 50°. For loading ammonia into trucks or railroad cars, this heating can be accomplished in many ways using either water, steam, electricity, or natural gas. The use of water requires some precaution to avoid freezing up of the tubes or the shell. When employing water, one should never forget that liquid ammonia is 60° below the freezing point of water.

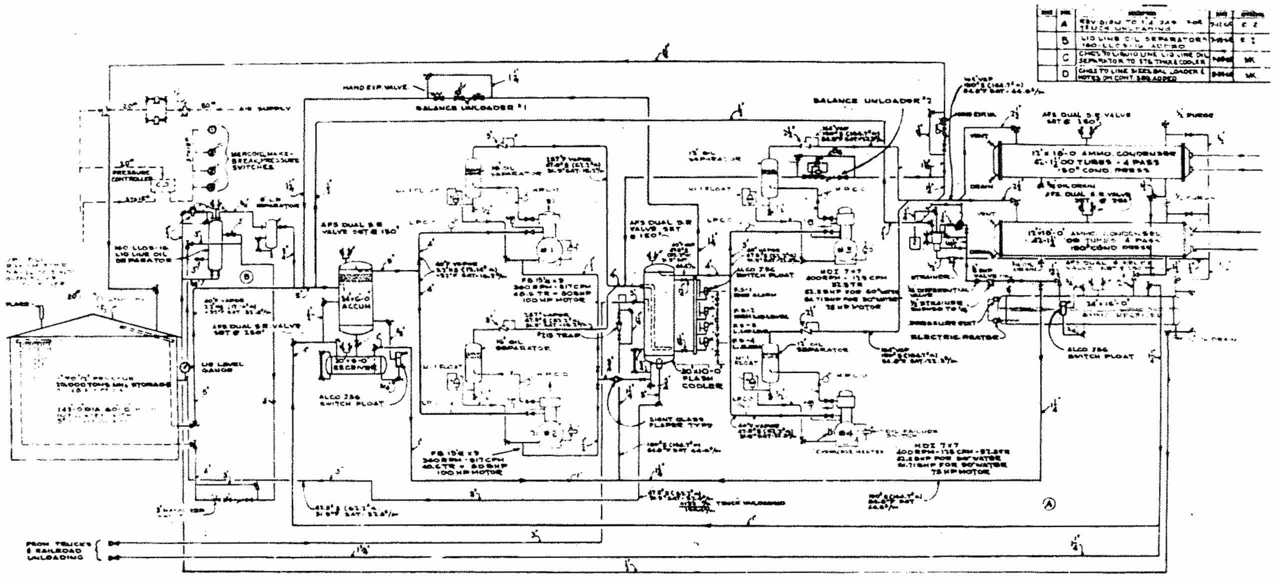
Specific installation (W. G. Strauch)

We of the Frick Co. do treat an atmospheric ammonia storage system as a fairly simple -28°F refrigeration system. Two-stage compound systems are applied by Frick Co. on a very regular basis, and we feel that a compound system is most necessary at temperatures and pressures this low to prevent the high compression ratios necessary on single-stage systems. Of course, a high compression ratio job means higher maintenance on all reciprocating compressor equipment.

Normally speaking, when we design an ammonia refrigeration system, we continually stress the necessity of safety devices, and the safety devices are good practice, for any system involving ammonia as a primary refrigerant.

Let's follow via photographs a typical system. We will, of course, emphasize the numerous safety devices on such a system.

Figure 3 is a long shot of the tank from outside the property line. This equipment is installed in a fertilizer plant. We are looking at the 10,000-ton storage tank. The overhead conveyor handles rock phosphate



PROPOSED CONTROL SEQUENCE:

Sequence of control starting at 100% capacity will be as follows:

A. On tank pressure fall, switch 1 breaks, stopping compressors 2 and 4 thereby reducing capacity from 100% to 50%.

B. On further fall in pressure, switch 2 makes, thus energizing the solenoids of the balance loaders 1 and 2 reducing capacity to a fixed setting between 0% and 50% (depending on setting of hand expansion valve on balance loader 1).

C. On further fall in pressure, switch 3 makes closing the balance loaders solenoids and opening the hot gas bypass solenoid allowing the discharge gas from compressor 3 to flow directly back to storage tank thereby adding heat to the tank.

D. On further fall in pressure, switch 4 makes starting compressors 2 and 4 (booster 2 start is delayed for a predetermined time to reduce electrical surge current and to hold down the intermediate pressure). Thus the heat input to the tank is at a maximum.

E. On rise in pressure, switch 4 breaks stopping compressors 2 and 4, reducing the heat input to the tank by 50%.

F. On further rise in pressure, switch 3 breaks closing the hot gas bypass and opening the balance loaders thus stopping heat input to tank and starting refrigeration by an amount set by the balance loaders (see B).

G. On further rise in pressure, switch 2 breaks closing the balance loaders leaving the system on 50% capacity.

H. On further rise in pressure, switch 1 makes starting compressors 2 and 4 (as before, a time relay delays the start of the booster) thus the system returns to full capacity.

Under the above control sequence, compressors 1 and 3 never stop.

Figure 2. Flow diagram for low temperature atmospheric ammonia storage.

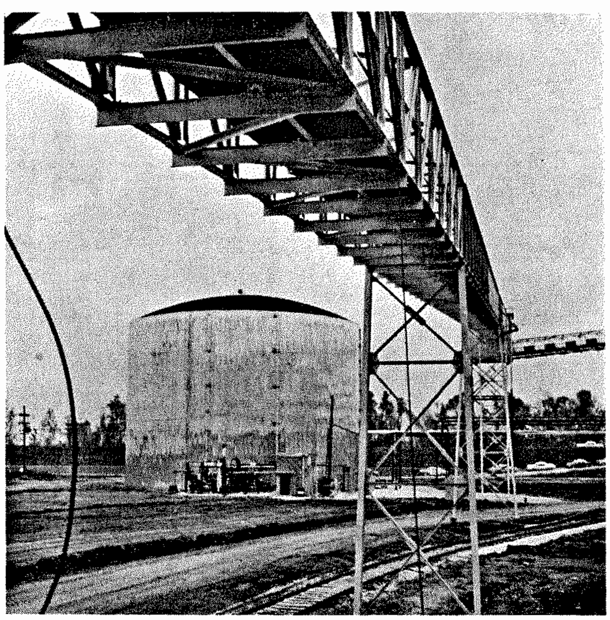


Figure 3. View of ammonia tank.

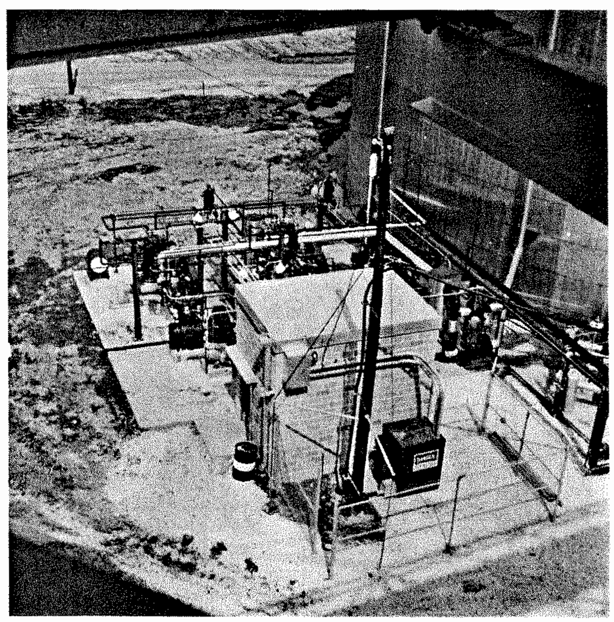


Figure 4. Compressor area.

from the same unloading area as the barges. All the equipment is installed outdoors and we have a 100% stand-by.

Figure 4 is a view of the compressor area from the phosphate conveyors. All the controls and equipment are in the small concrete block building. Over on the right you will notice the river water lines for condensing purposes. They are here in the foreground and the suction line drops down to the right.

In Figure 5 is shown the suction accumulator which is 36-in. diameter by 8-ft. high with a 300-ft. pipe coil wound around the inside. This means that any liquid that falls into the accumulator will boil off from the heat brought through by the liquid passing through the internal coil. Up at the top left is a purger and the high level shutdown and alarm. On this unit we have two Magnetrols. One level of the Magnetrol rings an alarm—the other shuts down the compressor if due to some malfunction we have a flooding of refrigerant out of the storage tank.

Fully automatic controls

Figure 6 is a long shot of two of the 11 1/2 by 8 booster compressors with 50-hp motors, all operating under fully automatic controls. Figure 7 is a close-up of the 11 1/2 by 8 booster. Note we have capacity control. This compressor has 25% and 50% capacity reduction. The booster discharges into the scrubber-type oil separator; fully automatic oil-return systems return the oil to their respective crankcases. Moving down the flow, Figure 8, we have the intercooler. The boosters discharge into the intercooler and the liquid level of the intercooler is maintained by a fully mechanical float. Here we are emphasizing the necessity

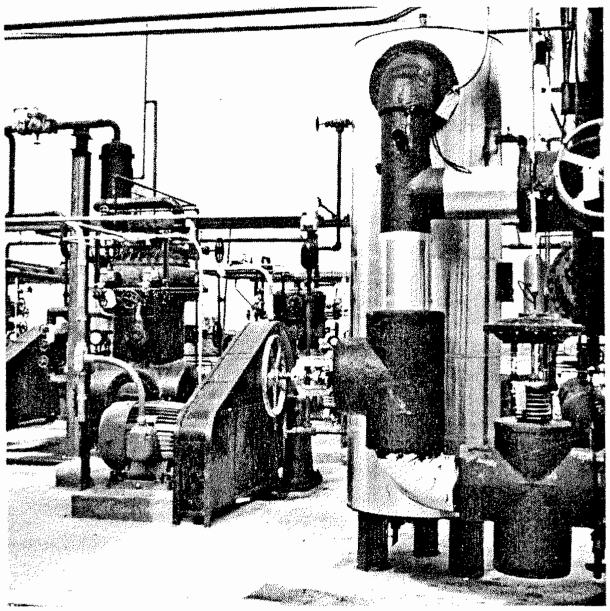


Figure 5. Suction accumulator.

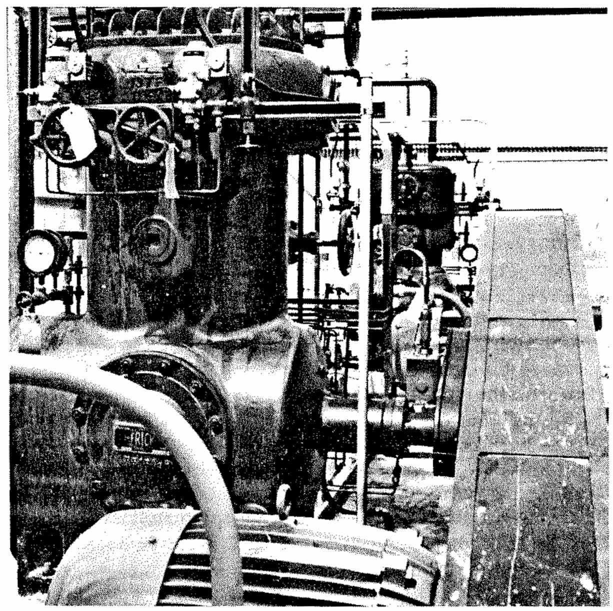


Figure 7. Close-up of compressor.

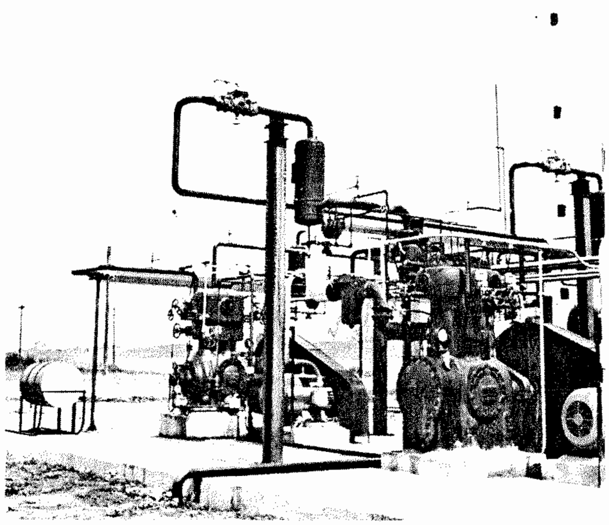


Figure 6. Booster compressors.

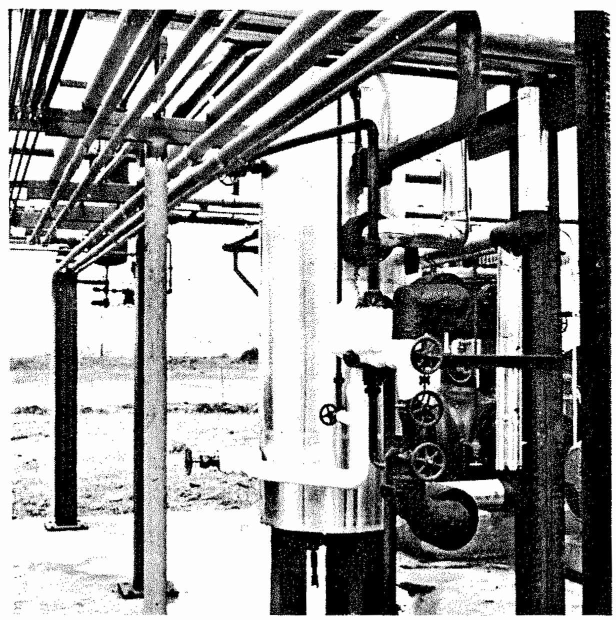


Figure 8. Intercooler.

of safety. We have a three-valve bypass which enables the float to be worked on or maintained without shutting down the system.

In Figure 9 we find that the desuperheater gas is entering the high stage compressor. This is operating on a 25 lb./sq.in. suction on an 8 by 8 compressor with a 75-hp motor. This entire plant is operating under automatic control.

Oil failure switch

You will note in Figure 10 that all compressors have oil failure switches and weather-proof construction. Of course, the compressors all have external lubricators. In Figure 11 we find the cylinder wall thermostat that shuts down the compressors in case of overheating and also rings in an alarm.

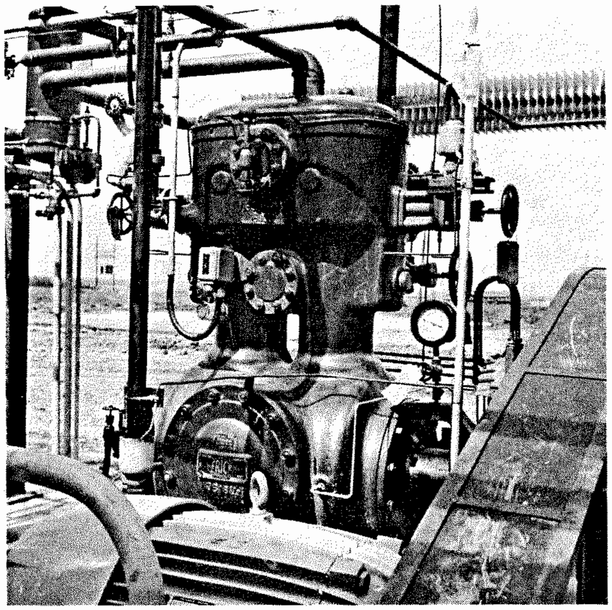


Figure 9. Desuperheater gas entering the high stage compressor.

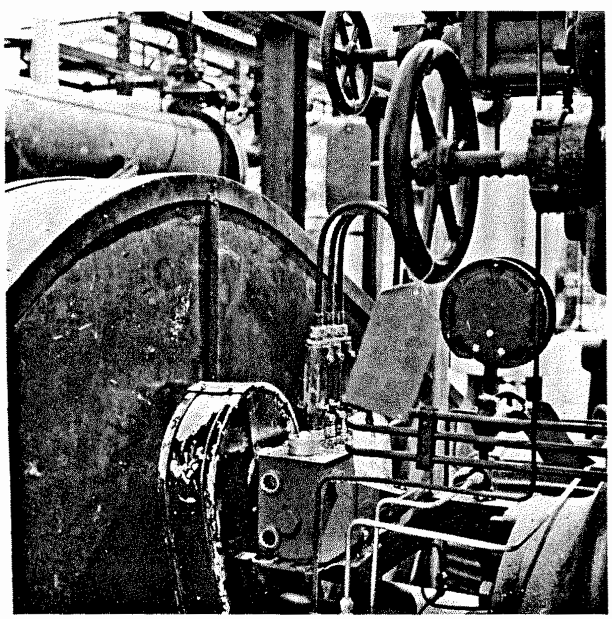


Figure 10. Oil failure switches and external lubricators.

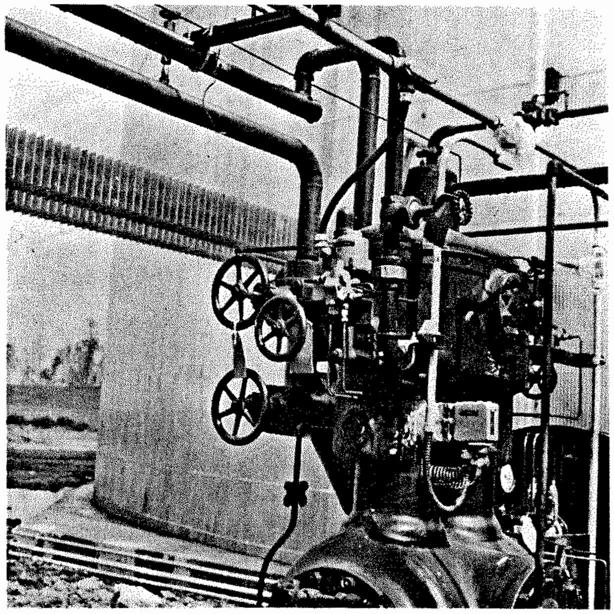


Figure 11. Cylinder wall thermostat.

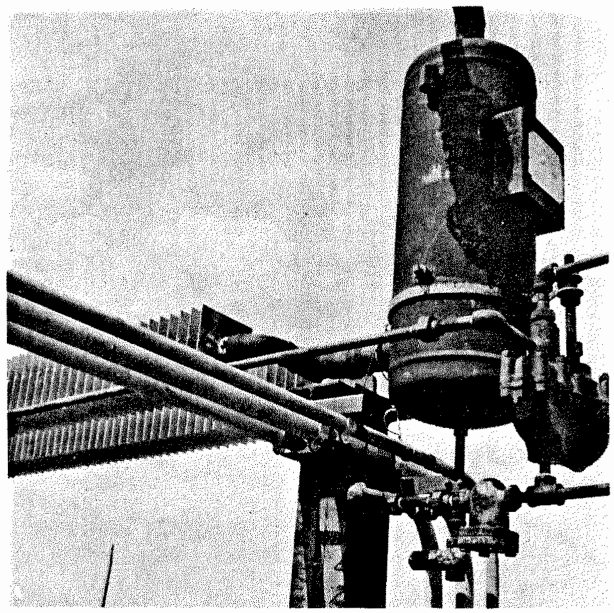


Figure 12. Oil separator.

Figure 12 shows the oil separator from the 8 by 8's. Note the air-cooled desuperheater. Notice also the wheel removed from the condenser inlet valve. This is not necessarily recommended by the Frick Co. It is a customer preference.

In Figure 13 we see the complete condensing system. In this system we have a water-cooled condenser utilizing river water for condensing and, of course, the receiver. Note the dual relief valve on the receiver. We have a Magnetrol which senses the level in the receiver and operates this electric valve shown in Figure 14. The pressure is relieved through the hand expansion valve on the left.

Relief valves

In Figure 14 we have a close-up of this relief valve. Across this hand valve is the actual pressure

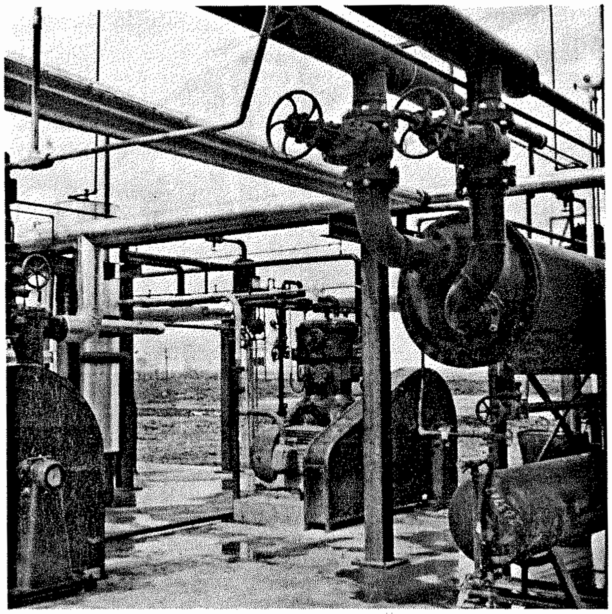


Figure 13. Condensing system.

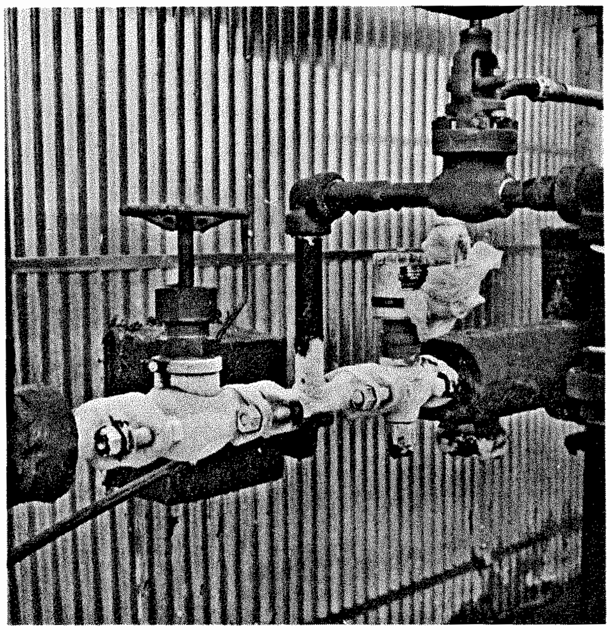


Figure 14. Relief valve.

relieving from the normal 185 lb. condensing down to the tank pressure. Of course, the liquid stream has first passed through the coil of the suction accumulator. This stream is passed through the coil in the intercooler accomplishing as much cooling as possible on the higher suction pressure levels.

The liquid enters at the top of the storage tank. The winding staircase climbs to the top where the liquid enters, also the D-P cell that controls the compressors.

In Figure 15 you will notice how the D-P cell senses the atmospheric pressure and tank pressure and sends a signal to the Foxboro recorder controller with an 8 step rotax. Notice the closeness of control. The electric control valve for the booster compressor is controlled by the rotax.

On the intermediate pressure we have a Honeywell pressurestat that measures intermediate pressure and operates on the Honeywell step controller that controls the capacity control on the 8 by 8 compressor. Corresponding pressure gauges are shown in Figures 16 and 17. The pressurestats are shown in Figure 17.

There are many important safety features on the big compressor including heavy-duty construction, 327 to 400 rev./min., built-in relief valves, 4-valve manifold, and, of course, the floating spring-loaded heads. If they get a slug of liquid, they can pass it along without serious damage.

Underslab heating

There are several safety features applied by our customer to this system. First is the underslab

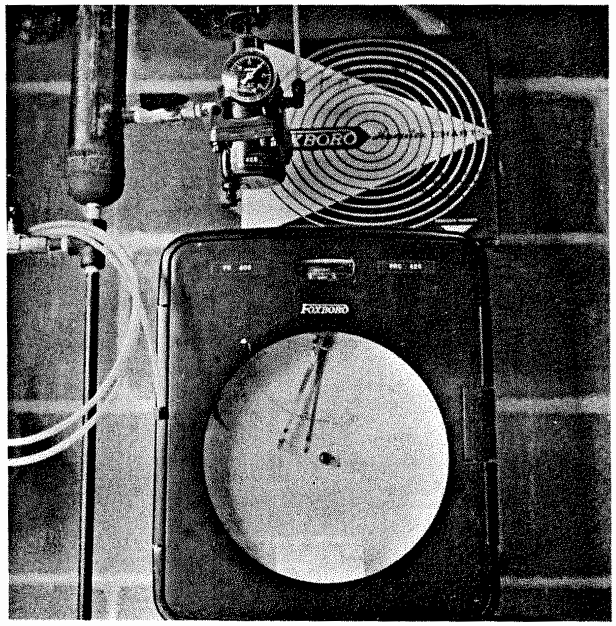


Figure 15. Recorder controller.

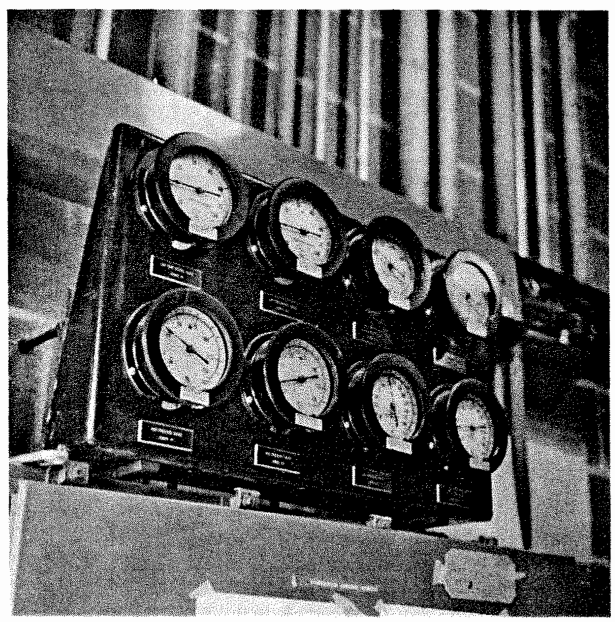


Figure 16. Pressure gauges.

heating. There are heater cables on approximately 2-ft. centers. There are a few extra conduits in case they are necessary. The controller keeps the temperature of the slab up to 50°F. On the tank top is a combination pressure relief valve and vacuum relief valve. This is a Shan and Jurs valve. This installation also has Shan and Jurs tank level gauge. The control house is very close to the tank and houses all the starters and controls, which are NEMA 1 construction.

High and low pressure cutout

In Figure 17 we can see a high pressure cutout and a low pressure cutout for every compressor, and a pressure gauge for every compressor. Note that the suction pressure from the low side reads 0-lb. suction, with a 30-lb. intermediate. This is a fairly cool day with cool river water, and we are condensing at 155-lb. high stage discharge. Notice the Foxboro controller and, of course, the manometer. It is reading a little more than 3 in. of water pressure. There is a separate small air conditioning system to control this particular control room.

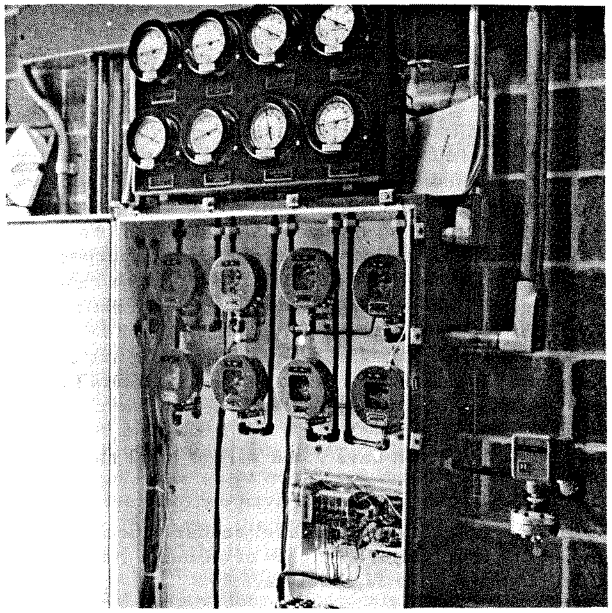


Figure 17. High and low pressure cutouts.

DISCUSSION

WELLS—American Oil: The subject of block valves and relief valves was mentioned before. I didn't see any block valve or cock under the Shan and Jurs valve. What do you do if that relief doesn't shut, or leaks, etc.? Do you have a problem with emptying the tank to repair it?

STRAUCH: We certainly do. We design and build refrigeration systems; in this particular case, we merely supplied the unit.

EDDY: We have on our equipment dual relief valves so that we can block them off independently to avoid that problem.

Anonymous: I would like to have some comment on the pressure gauges which are in the switch room. I would like to know whether these are transmitter pressure switches, or are they directly connected to the compressor with ammonia gas?

STRAUCH: The pressure gauges are direct acting. This means they take the reading direct from the suction and discharge of the compressors and are just indicating gauges.

Anonymous: This in effect means that if you have a gauge line failure, you will have release of ammonia gas into the switch room itself. Is that correct?

SCHROEDTER: We always have shut-off valves in front of the gauges, either at the gauges or at the take-off from the compressors. If something goes wrong with the gauge, we can, for a certain time, close this line and replace the gauge or put a correct gauge on.

Anonymous: In regard to the question on relief valves on the storage tanks. Last spring we had problems on several installed on top of the tanks. They are flanged valves. What we did was lower the control point down to a minimum position on the tanks, loosen the valves and try to blind them. You have to realize that this pressure is low enough that if adequate safety protection is provided, the man working there has no particular problems.

WALTON—SunOlin: Some years ago when I was with Atlantic, we had an ammonia refrigeration system (connected with an alkylation plant) that had ammonia fittings on it. When we did decide to replace these fittings, this was a problem because ammonia-type fittings are not generally available. We gradually replaced most of our ammonia-type fittings with ring-type joints. This is something you might want to consider.

Another question I had is that I noticed, on some of your figures, sweating lines. This creates corrosion problems. I never saw paint that would adequately stay on a sweating line. How do you propose to correct this or are you content to allow these lines to sweat?

STRAUCH: This particular installation was sold by our company to a customer who subcontracted the erection out to local contractors. With regard to sweating, a group of these pictures were taken prior to installation. I'd say if you went over the job, you probably wouldn't find any lines that are not covered with insulation. We do not, as a company, like to see lines sweat. Sweating lines should be covered. We have a problem too in our part of the country with river water lines sweating.

Anonymous: Would you comment on your method of servicing relief valves?

STRAUCH: I'd say two things. First of all, we market a fairly economical dual relief valve. The largest we make is 2-in. size. We like to sell the dual-valve manifold, so that you can have one valve on while the other valve is being taken off.

As far as the problem of availability of the ammonia-type valves, we, of course, have been in the refrigeration business, and our industry has adopted this type of valve. It is (1) a more economical valve, and (2) they are in wide supply throughout the country. We have them in warehouses all over the country, in every major city of any size.

Anonymous: I notice that you are putting your receiver ammonia directly back to the storage tank rather than the flash tank. This is unusual as far as my experience has been. Could you comment on that?

SCHROEDTER: The high pressure receiver accumulates the liquid from the condenser and then from there it will be pushed back through the flash cooler back to the storage tank. On the first flow diagram, we pushed it through a coil; and, on the second diagram, we flash cooled it. But it is always used for cooling purposes, because the liquid that is in the high pressure receiver is around 90° and we want to cool it down to about 30 to 40° before it goes into -28° storage.

As Mr. Eddy said, both of these jobs are custom built, and the customer in many cases specifies the way they want to handle it, and we build it that way.

Anonymous: Do you have some sort of level stabilizers within the tank.

STRAUCH: No. We have a level reader which is reading in this case within an eighth of an inch. As far as I know, the controller is accurate.

ROMANOWSKI—Canadian Industries, Ltd.: I would appreciate hearing any comment on how you design the relief valve to allow for possible fire hazards.

STRAUCH: We have a formula. In case you do have a fire, you have quite a problem of releasing the pressure. Might I say here that it would probably be very fine if people who have more experience in actual tank design answer this question rather than we who are in the refrigeration business.

STOCKBRIDGE—Southern Nitrogen: The men speaking are from the Frick Co. They design the refrigeration system and only the refrigeration system for this installation. The level gauges and relief valves on the tank are not designed by Frick and these gentlemen just don't know the answer. I can say from experience, in answer to Mr. Romanowski, that we have a Shan and Jurs-type level gauge on our tank which has been very satisfactory. We can read it within a sixteenth of an inch.

SACKER—Collier Carbon and Chemical: Have you considered the use of nonlube type compressors? Eventually, I believe, you are going to get a lot of oil in that storage tank.

STRAUCH: First, we do not manufacture nonlubricative-type machines. Second, nonlubricative-type machines are much more expensive than package refrigeration machines that we use. Third, I was involved in an installation in St. Louis four years ago, and at that time this particular company was quite concerned about oil carry-over in the tank. Last year several of us visited that particular tank and the question we asked was, after the unit had operated for three years, whether oil was a problem or not? This involved two 15,000-ton tanks. These tanks, after three years of operation, have no problem whatsoever as far as oil is concerned. We were told, first, that whatever oil your units are putting into the tank is sold with the next load of ammonia. This is a relatively small amount of oil, less than 5 ppm. Second, oil in a refrigeration system is something that we are very conscious of and, at the installation I referred to earlier, the people who operate the plant tell me that the desuperheaters we have on the system, as far as they are concerned, are not putting oil into the tanks. I don't believe that this is a cumulative thing; we like to think that the oil problem has been blown out of proportion.

FESER—Illinois Nitrogen: The statement was made that the fog or particular matter existed about the level of the cryogenic tank. Do you have specific evidence that supports that this is so?

SCHROEDTER: We know that we have slop-over on pressure changes with weather and so on. And we never climbed into a tank to see the fog, but there must be something like it, or mist. In other words, how would we get liquid slop-over into the suction line when we have taken the suction from the top of the tank at the center at the highest level above the liquid. That is the only explanation.

COMEAU—Monsanto: Are you reasonably sure that the slop-over did not come from the purger system, rather than from the storage tank?

SCHROEDTER: The purger system is not connected with the storage tank. The purger is only hooked up to our refrigeration system, and it would never touch the tank.

COMEAU: Doesn't the ammonia from the purger system, the cooling ammonia, the refrigeration, go back to first stage?

SCHROEDTER: No. The suction from the purger goes back to the first accumulator. It never touches the tank. It goes into the accumulator, there is where you find ammonia. The accumulator is designed to prevent any slop-over. It has a high level float switch as protection, has a liquid level gauge, etc. My point is that we recognize that you found liquid in the accumulator. I assume it will tell you where you got the liquid from.

The liquid could have come from the purger rather than from the storage tanks. Not all of our purging goes back to the first stage. Some of it goes to the intermediate and yet we still design for liquid coming from the tank.

COMEAU: Have you found liquid in those cases in the first stage separator where you have a purger that goes into the second stage? The liquid can come from the purger, but I can't imagine it coming from the tanks. I was wondering how good the evidence was that it did come from the tanks and not from the purger. If that is happening on an installation of ours, we would certainly have an immediate indication from the frost from the purger into the low stage. We have this liquid problem coming into the machine. Of course, we are watching every possible place it could be coming back from.

SCHROEDTER: One theory is that there is a mist or fog of the bubbles rising from the bottom of the tank, bursting on the top and, due to the pressure drop in the lines, somehow or other there is liquid in the machine. Another theory evolves around having buildup of liquid in the accumulator during loading of the tanks which involves flashing of the tank. You may have several pounds pressure difference between what is being unloaded, for example, a barge, and the tank. There has to be some sort of fog or mist occurring during the flashing process.

WELLS: We have a large tank and we have no knockout drum in the suction line at the compressors. We have never had any indication at all of getting liquid in the large suction line from the tank. We found it hard to imagine a better large size knockout drum than the tank itself. We have had no trouble with it.

SCHROEDTER: This is one of the devices we like to see on a refrigeration system. We may use it only once in every hundred years, but I am sure glad when it's there.

FAATZ—Foster Wheeler: I presume that the refrigeration system is designed primarily to make up heat leakage into the tank. On the other hand, when you unload a barge in a very short period of time and the barge liquid temperature is a degree or so higher than the tank temperature, you ought to get a very heavy heat load or vapor load on your compressor. Is there anything in the design of this compressor to take care of the unloading heat influx from the barge to the tank?

EDDY: Yes. On an installation of this type, we have certain specifications. If a customer wants to unload at a given rate, he is going to have ammonia at a given temperature, within the tank. That, of course, is where the design criteria comes about. In an installation of this type, we call upon the stand-by compressors to work during the unloading process. That's normally the case for normal heat infiltration for one compressor to run. Both compressors run during unloading time, and the unloading rate is governed by the ability of the machines to hold pressure. There are two things to be taken care of—the effect of temperature of the ammonia entering and the displacement of the volume of the ammonia.

FAATZ: Then the demurrage on the barge may be determined in part by the capacity of the refrigeration system to load and unload. You may have to hold the barge three extra hours in order to make up for this difference in temperature between the barge and the tank.

SCHROEDTER: Well, the barge is supposed to arrive at -28°F but sometimes it arrives at -27°. I think the way facilities are, the way ammonia is being handled today in most cases, it is being unloaded at the barge at somewhere close to -28° and handled at -28°. Some barges are large enough to pull ammonia down from, let's say, 50 lb. pressure, or 20° to -30°, down to atmospheric. In other systems, refrigeration equipment on the barge is just large enough to hold it during transit. However, you are right, the speed of unloading is based upon how cold this ammonia is when it arrives.

BORST—W. R. Grace: One of the most important factors to be considered in designing your refrigeration load for barge or ship unloading is the horsepower on the unloading pumps. You can have ammonia coming into storage at storage temperature but still have to supply refrigeration to remove the energy imparted to the ammonia by 300 to 400 hp unloading pumps. This means 64 to 85 ton of refrigeration. The refrigeration due to vapor displacement must also be handled by the compressors.

Referring to the subject of suction knockout drums for the first stage of refrigeration compression, we have these in our older terminals. On most of our recent terminals we have deleted them. As Mr. Wells said, we feel that we have the biggest separator that we could possibly have, the storage tank. But, the man from Frick is right in that in the region immediately adjacent to the liquid inlet there is a fog or mist during filling. We had a rather unfortunate circumstance in which a liquid inlet was inadvertently located rather close to the vapor outlet, and we did have liquid coming over in the suction line. Relocating the liquid inlet to the other side of the storage tank solved this problem.

The suction temperature of the low stage compressor in most of our storage terminals runs far above the saturation point with no liquid ammonia present. There are, however, two other sources of liquid that must be designed for. In our older terminals, with low stage suction knockout drums, the refrigeration vapor from the purge condenser and blowdown vapors from the tank trucks and cars were originally piped to the knockout drum. A stuck purge condenser level control valve or carrier slop-over would put liquid into the knockout drum. The high level alarms and immersion heaters on these drums were found to be inadequate protection for the compressor. All miscellaneous vapor streams have now been piped to the top of the storage tank.