A METHOD FOR DETERMINING FILLING DENSITIES FOR ANHYDROUS AMMONIA TANK CARS

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In 1958 Phillips Petroleum Co. filled two 10,000-gal. tank cars (one insulated and one uninsulated) with anhydrous ammonia (Two other identical tank cars were filled with LPG) and set them on a siding. One then measured the liquid ammonia temperatures that occurred during both the summer and winter. If one knows the liquid temperature, it is a simple matter to calculate the point at which a container becomes liquid full for various starting filling densities. However, choosing the liquid temperature upon which to base a recommendation for the starting filling density becomes an extremely complex task.

Safety, economy, and utilization

First consideration must be given to safety of the public and of the operating personnel. Optimum economy of operation and utilization of the nation's tank car fleet must be considered, also.

From these tests we determined the relationship between ambient temperature and the liquid temperature of the anhydrous ammonia inside the tank car. One can, of course, plot the measured ambient temperatures and the recorded liquid temperatures and establish a curve. The problem then is what is the relationship of the ambient temperature conditions encountered during the test to expected ambient conditions in other parts of the United States? To answer this question a most elaborate study of United States Weather data was made by the United States Weather Bureau. These weather data were then used to determine conditions to be encountered in public transportation of ammonia tank cars. A study of the test data secured, also revealed, that for liquid volumes of 10,000-gal. tank car magnitude, that the resultant liquid temperatures were dependent upon not only the ambient temperature of any given day but also dependent upon the ambient temperatures of previous days. This information and complete test data are contained in the reports of the tests (EDR-410).

Liquid ammonia temperature

What is the ammonia tank car filling density problem? Briefly stated, it is this: "How warm does the liquid ammonia get inside a tank car?" If one were forced to solve this problem by considering only two variables, one could take experimental data, and plot observed maximum liquid temperature against observed maximum ambient temperature. One would then draw the best line through the data, and read what the maximum liquid temperature would be at some extreme ambient temperature. The answer would probably be considered a good one, although it would contain much unexplained variation. That is, an actual observation might vary considerably from the predicted value. To compensate for this, one would have to add some arbitrary amount to the predicted answer.

Reducing unexplained variation

If one were to consider not only the ambient temperature of today, but also the ambient temperature of yesterday and again plot the problem, this time with 3 variables, one would get a better answer; that is, an answer containing less unexplained variation.

The same would be true if one considered 3 previous days, or 4, or 5, etc. The more days one considers, the less the unexplained variation, and the more reliable a predicted result. This is what was done. A mathematical picture was drawn which shows the relationship between daily maximum liquid temperature and the ambient temperatures of the day under consideration, and the several previous days. The number of previous days necessary to include in a picture was determined in each case by what the tank car contained, and whether or not the tank car was insulated. For ammonia in an insulated tank car, it was necessary to include 30 previous days. This meant a total of 63 separate variables. Without mathematical analysis, the problem would have been insurmountable.

Past weather conditions

Once the empirical equations were obtained, the next step of the problem was to use these tools to investigate weather conditions of past years for various locations in the United States. This required the cooperation of the U. S. Weather Bureau. They recommended a network of locations for study. With money advanced by the Compressed Gas Association, the maximum and minimum ambient temperatures were obtained for each day of the summer and winter months, for the 25 years from 1933 through 1957, for each location in the recommended network, Figure 1.

Using empirical equations and an IBM 7094

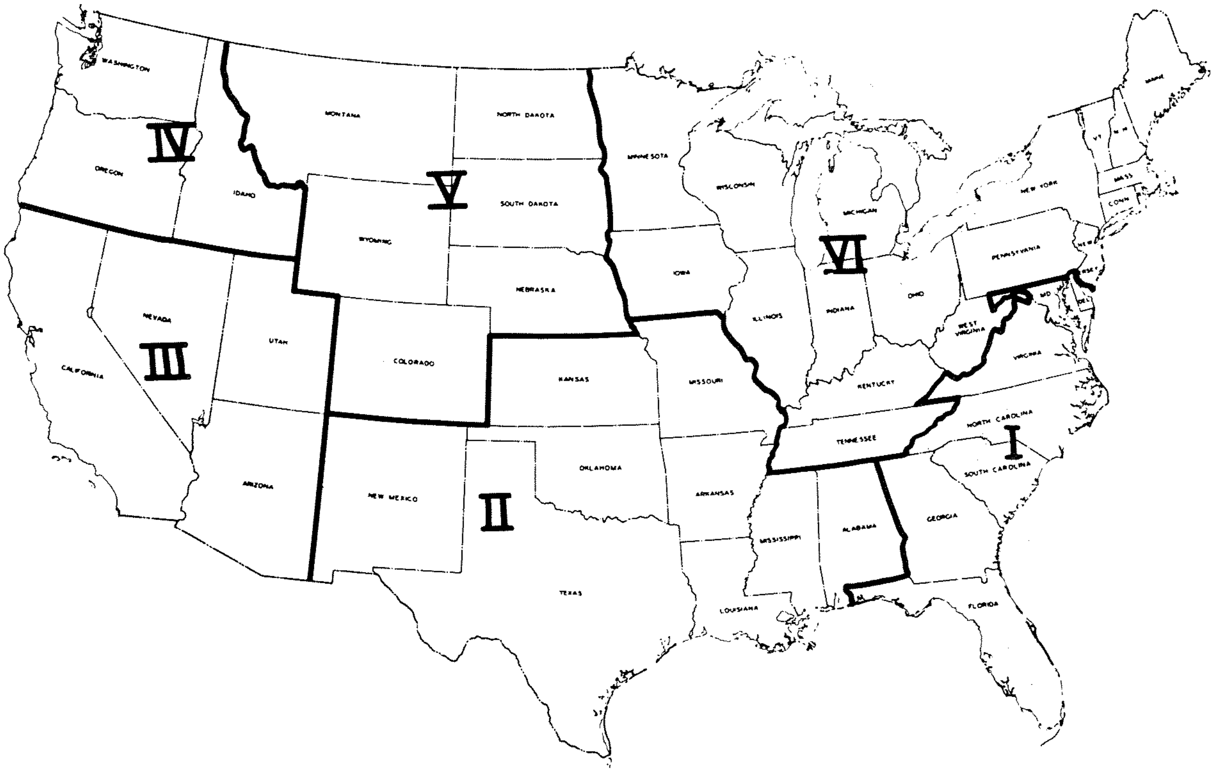

Figure 1. A division of the United States into areas as set forth in the Compressed Gas Association weather study.

computer, we calculated what the maximum liquid temperature would have been on each day of the summer and winter months, for each of the 25 years, at each location, for each type of service. After the liquid temperatures for each day were calculated, the highest liquid temperature for each year, for each season, for each location, for each type of service, was sorted out.

Law of expected extremes

The next step of the problem solution utilized a method taken from the design of flood control dams. One must decide on some reasonable design criteria that one can live with and be able to afford. The law of expected extremes, and a reasonable return period provide the answers. The law of expected extremes, developed by Dr. E. J. Gumbel, is a tool used to determine how often a given size flood will occur, on the average, based on the past flood records.

Using this law, one can intelligently decide how high to build a dam. One can build one of modest height and cost, and be protected against the largest flood expected, on the average, every five years. (Saying it another way, one can build a dam such that one would expect to have the design capacity of the dam exceeded once every five years-on the average.) Or, one could build a higher dam, and have the capacity exceeded only once every 50 years, or still higher, and have the capacity exceeded only once every 100 years. But, note this, one is unable to build the dam high enough to provide absolute protection. That would require a dam infinitely high.

Return period

Now, how is the law of extreme values to be applied to filling densities? Well, one could fill cars so full that when sitting in a given location, they would become liquid full every year. This would be operating on a 1-yr. return period. One could design filling densities on the highest liquid temperature to be expected once each 5 years, or one could design filling densities on the highest liquid temperature to be expected once every 100 years. With the empirical equation, the large body of weather data, and the resulting calculated yearly extreme temperatures, one has all the information to make an informed and intelligent decision.

Eight charts for liquid ammonia

Figure 2 is a replica of one of the charts in report EDR-410. There are 8 such figures in the report, one for each of four types of service, for both summer and winter seasons. This chart shows the lines of expected extreme liquid temperatures for summer operation of an insulated tank car of anhydrous ammonia, based on weather information at each location in the network. It is quite important to remember that this study is primarily a study of weather. It shows how often the weather conditions capable of causing a certain maximum liquid temperature will recur. The study shows nothing about the probability of a tank car being at the location when the extreme weather occurs, or staying at the location long enough for the full effect of the temperature extreme to be realized. The small probability of a tank car being at the location at the time of the weather extreme and staying there for the required length of time tends to stretch the return period between exceedings of actual design far beyond the figures shown on the charts. It is with this fact in mind that one recommended the adoption of a 15- to 20-yr. return period—at a suitable location—as the criterion of filling density design.

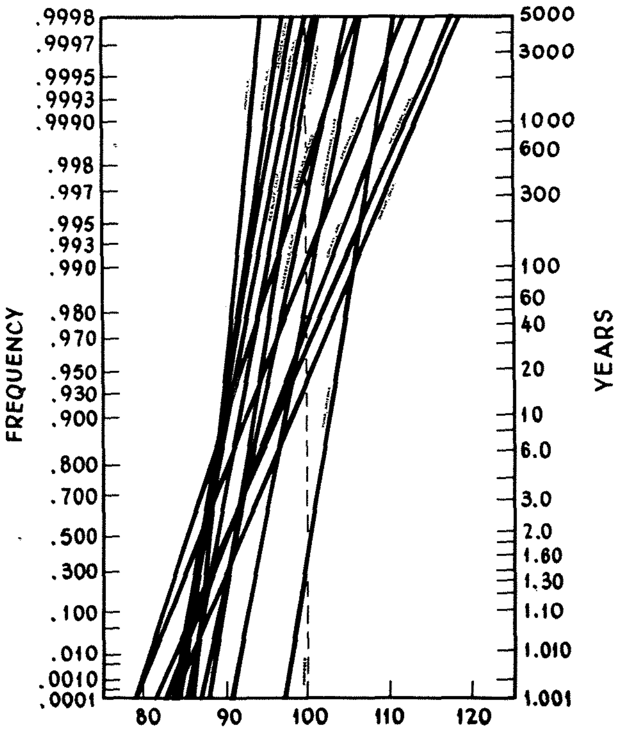

Figure 2. Expected extreme liquid temperatures, summer operation, insulated tank cars, anhydrous ammonia service.

Winter—58.4%; Summer—60.1%

Test and analysis of the data have led to the conclusion that summer filling densities for anhydrous ammonia tank cars can be 58.4% and winter filling densities can be 60.1%. These conclusions have been approved by the Compressed Gas Association, The American Petroleum Institute, the Manufacturing Chemists Association, the Agricultural Ammonia Institute, the National Liquefied Petroleum Gas Association, and the Association of American Railroads. It was mentioned earlier that safety of the public and of the operating personnel must be given first consideration. This has been done in formulating recommendations. Actually, the recommendations were purposely made on the conservative and safe side.

Safe recommendations

The recommendations are on the safe side because:

1. Extreme conditions upon which the filling densities were based are statistically not likely to occur when a tank car is at that location for the required length of time. Therefore, the return periods are conservative.
2. Peak shipments of ammonia occur in the spring; and, therefore, will not be subjected to maximum temperatures encountered in the summer. This makes the proposed filling densities very conservative for the bulk of the movement of product.
3. Shipments in the Northern, New England, Southeastern, and Middle Western states will always be on the safe side because filling densities are based on extreme conditions in the Southwestern states. Such extreme conditions do not occur in the other states.
4. Filling densities are based on tank cars being stationary in the extreme temperature region for up to 30 days. In actual practice the tank cars will be moving through this area and exposed for a much shorter period of time.
5. The test data were obtained on tank cars which were placed in a north-south direction. This is the worst condition for heat absorption. In transportation the cars will be moving in every direction; therefore, the heat absorption will be less.
6. Tests were run on 10,000-gal. tank cars. Most tank cars going in service today are 30,000-gal. tank cars. With a substantial increase in the volume of product, the temperature increase of the liquid will be less when exposed to the same conditions of ambient temperature. This is, therefore, a built-in additional safety factor.
7. It was concluded, based on all the extreme conditions chosen, that one could safely base the filling density on less than a 5-yr. return period. Instead, a 15-to 20-yr. return period was recommended as another additional safety factor.
8. As a further safety precaution we checked these empirical formulas against two sets of independent data and calculated what the liquid temperatures should have been. They predicted the observed data with excellent accuracy, thereby, verifying the soundness of this solution to the problem.