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official must recognize the futility of controlling these factors. If then the direct-pressure system is inherently wrong, the only relief lies in its elimination or modification.

## DISSOLVED AIR IN GASOLINE

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All commercial gasolines contain dissolved air, for at some time or other between the refinery and the engine they are exposed to the atmosphere. Some gasolines contain more air than others, for the amount which will dissolve depends upon the volatility of the gasoline and the conditions under which it is stored in dispensing systems. The air which is in solution can not be seen, for it is so finely subdivided that it is invisible. It only becomes visible in the form of bubbles when the pressure is released or the temperature is increased. It is the release of pressure which makes gasolines appear to boil when pumped into the visible container on the pump, a phenomenon observed by every motorist. While this boiling may be due to dissolved gases other than air, it is more commonly caused by air coming out of solution.

The amount of air which dissolves in gasoline under various conditions is a matter of widespread importance. The person who stores gasoline should know how much of his storage loss is attributable to air coming out of solution, thereby displacing gasoline vapors. The dispenser of gasoline is interested in the effect of dissolved air on the accuracy of the metering device. The motorist wonders what relation exists between boiling at the pump and stoppage of the engine due to vapor lock or formation of bubbles in the fuel feed line. The designers of storage and dispensing outfits and the automotive engineers desire to provide equipment which will eliminate the effects of dissolved air. Comprehensive answers to all of these questions can not be given at present, but the basic problem with regard to the amount of air which dissolves in gasoline under various conditions has been solved.

In order to obtain a better understanding of the significance of the problem of air solubility, let us consider what gasoline is. Gasoline *per se* is a mixture of a large number of substances—100 or more, perhaps even 1,000—composed of hydrogen and carbon and therefore called hydrocarbons. These substances all have different properties so that, for example, they boil at different temperatures and have different vapor pressures. Gasolines are composed of unknown numbers of these hydrocarbons present in unknown amounts, and because of this it is necessary to have some means of identifying different gasolines. The method used by the oil industry in this country consists in distilling the gasoline according to a definite procedure in a prescribed type of apparatus and recording the temperatures at which various percentages of the gasoline are distilled off. When water is distilled in such an apparatus, the temperature will remain constant throughout the distillation. However, with gasoline, since it is a mixture of hydrocarbons of widely varying boiling points, the more volatile hydrocarbons will distill off first, leaving the residual liquid less volatile and requiring successively higher temperatures to make it boil. Therefore, in dis-

tilling gasoline, the temperature will rise continuously as the distillation progresses, and there may be 300° to 400° difference between the temperature at which the first and last portions are distilled off. The curve obtained by plotting the temperatures at various stages of the distillation against the corresponding amounts distilled is the identification curve of the gasoline and is commonly known as the A. S. T. M. distillation curve.

There is one point on this distillation curve which is significant in connection with the various problems which have been mentioned, and that is the temperature at which 10 per cent of the gasoline is distilled over, usually called the 10 per cent point. This point gives information on such apparently unrelated phenomena as air solubility, vapor pressure, vapor lock in fuel feed lines, and the temperature at which engine starting is possible in cold weather.

In addition to the hydrocarbons, which are the main constituents of gasolines, there are normally present in solution a considerable amount of air and some water. When a gasoline direct from the stills at a refinery is exposed to the air on storage in a tank fitted with a vent hole, air will go into solution to an extent dependent upon the volatility of the gasoline, as represented by its 10 per cent point. If the gasoline is stored under air pressure, more air will go into the solution than when it is stored in a tank exposed to the atmosphere, for the solubility increases with pressure. When the temperature of the gasoline in the tank increases, air will normally come out of solution, for the solubility of air tends to become less at higher temperatures.

A large number of experiments on air solubility in a variety of gasolines over a range of temperature and pressure have recently been made at the Bureau of Standards. The gasolines were first freed from the unknown amounts of dissolved air present and then measured amounts of air were added. In removing the dissolved air, the gasolines were frozen in glass containers immersed in liquid air at a temperature of about -300° and while frozen, air was removed by means of a vacuum pump capable of producing a vacuum of about one-millionth of a pound per square inch. By repeating this procedure several times, all of the air was separated from the gasoline without pumping off any of the latter. By means of a special apparatus, measured amounts of air were added to the gas-free gasolines and experiments were made to determine the amount of air in solution in each gasoline at various temperatures and pressures. The temperatures used ranged from 0° to 100° F. and the air pressures from 1 to 20 lbs./in.<sup>2</sup> and each set of conditions was investigated with gasolines covering the range from very volatile natural gasoline aviation fuels to motor gasolines less volatile than those sold commercially.

The air solubility was found to depend upon the volatility of the gasoline in two respects. All gasolines exert a vapor pressure and the magnitude of this pressure depends upon the temperature and upon the 10 per cent distillation point of the gasoline. When a gasoline in a container is exposed to the atmosphere through a small opening, the total pressure above the liquid is atmospheric (14.7 lbs./in.<sup>2</sup> at sea level). Of this 14.7 lbs./in.<sup>2</sup>, a part is due to

the vapor pressure of the gasoline and the remainder is due to the air. Hence, under these conditions, air dissolves in gasoline under a pressure of 1 atmosphere less the vapor pressure. At 70°, the vapor pressure of an average motor gasoline is about 4 lbs./in.<sup>2</sup> while a very volatile aviation gasoline at this temperature may exert a pressure as high as 8 lbs./in.<sup>2</sup>. With these gasolines air would dissolve under pressures of 10.7 and 6.7 lbs./in.<sup>2</sup>, respectively, and as the solubility changes with the air pressure, different amounts of air would dissolve in these two cases. Since the vapor pressure of a gasoline is determined by the 10 per cent point, this point also determines the pressure under which air is forced into solution when the gasoline is stored in contact with the atmosphere.

When gasoline is stored in an inclosed container not open to the atmosphere, the solubility will also depend upon the pressure of the air. Thus, if the air pressure is 20 lbs./in.<sup>2</sup>, the amount of air which would dissolve in the two gasolines mentioned above would be approximately two and three times, respectively, that which dissolved when the gasolines were exposed to the atmosphere. It has been found that the solubility of air increases directly with the air pressure, so that if the solubility is known at one pressure, it can readily be computed at any other pressure by multiplication by the ratio of the two pressures.

Under the same pressure of air, all gasolines do not dissolve the same amount of air and the experimental work has shown that, for a constant air pressure, an aviation gasoline dissolves more air than does a motor gasoline. A very volatile aviation gasoline will dissolve about one-quarter of its own volume of air, whereas a motor gasoline of about the volatility of United States motor gasoline will dissolve about one-sixth of its volume of air, when both are put under an air pressure of 14.7 lbs./in.<sup>2</sup>. Under these conditions of constant pressure, the amount of air which goes into solution seems to depend upon the 10 per cent point of the gasoline.

It has been found further that when the gasoline is exposed to a constant air pressure, the amount of air in solution does not change with the temperature over the range from 0° to 100°. This, however, is not the case when the gasoline is stored in a tank open to the atmosphere, for under these conditions, there is an apparent change of solubility with temperature. Since the air pressure above the liquid in this case is the difference between atmospheric pressure and the vapor pressure of the gasoline, and since the vapor pressure increases with temperature, the air pressure and, hence, the solubility must decrease. With the aviation gasoline mentioned above, stored in this manner, the solubility at 70° would be 6.7/14.7 times one-quarter, or 0.114 volumes of air per unit volume of gasoline. At 100° the vapor pressure of this gasoline is approximately 13 lbs./in.<sup>2</sup>, so that the solubility would be 1.7/14.7 times one-quarter, or 0.029. The difference between these two volumes of air is the amount which would come out of solution when the gasoline is heated from 70° to 100°. In the case of the motor gasoline, the corresponding solubility at 70° would be 0.121 and at 100°, it would be 0.085 volumes of air per unit volume of gasoline.

When the air is actually in solution in a gasoline, the volume occupied by the gasoline is not appreciably different from what it

would be if there were no dissolved air in it. However, if the gasoline is saturated with air under pressure and this pressure is released, the air tends to form bubbles in the gasoline and the volume may be increased materially due to these bubbles displacing some of the liquid. Hence the accurate metering of gasoline must be done under such conditions that no bubbles of air are present while the liquid is passing through the meter.

One practical phase of the problem of dissolved air in gasoline lies in its application to the pumping of gasolines by suction lift. The height to which it is feasible to pump gasolines under these conditions is dependent not only upon the 10 per cent point of the gasoline, but also upon the amount of air in solution.

If a gasoline had no vapor pressure and no air in solution, it would be theoretically possible to lift it by ordinary atmospheric pressure to a height of about 45 feet. In the case of the two gasolines mentioned previously with vapor pressures of 4 and 8 lbs./in.<sup>2</sup>, respectively, at 70°, it would be possible to lift the motor gasoline 33 feet and to lift the aviation gasoline 21 feet without loss at this temperature, if neither contained any air. If, however, gasoline is saturated with air so that the sum of the air pressure and the vapor pressure equals the atmospheric pressure, then it will be impossible to pump the gasoline to a height by suction lift without pumping off some air with consequent loss of gasoline in the form of vapor. The height to which a gasoline can be pumped under these conditions depends upon the efficiency of the pump for removing gas. While the loss may not be excessive if the suction lift is less than the theoretical height for an air-free gasoline, it certainly will be excessive if attempts are made to pump it to heights greater than that determined by the vapor pressure.

In all of the preceding discussion, it was assumed that the gasolines contained the maximum amounts of air which they could dissolve under the particular conditions, and the solubility data obtained at the bureau represent those maximum values, which would be reached if a sufficient time were allowed for the air to dissolve. While gasolines are normally saturated with air, this is sometimes not the case, for it takes time to absorb all of the air which will go into solution, and the rate at which this occurs is dependent upon various conditions, such as the extent of the surface exposed to the air and the amount of agitation. Furthermore when air comes out of solution due to release of pressure, it takes time for the air to form bubbles and rise to the surface. The extent to which the maximum amount of air will come out of solution to reach the saturation value under the new set of conditions will depend upon the design of the specific apparatus and upon the specific conditions under which the release of pressure occurs. The rate at which bubbles form and grow in any dispensing system will be affected by the rate of flow through pipes of different diameters, by changes in the direction of flow, by pressure gradients, by constrictions, and so on. That is the reason why no general answer can be given covering all types of dispensing systems. The maximum solubility under each set of conditions can be stated, but, in practice, bubble formation in any system is an individual problem for each type of installation.