Fire Hazards Analysis

for the

BaBar Detector Project

Prepared for

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Appendix A

Analysis of Flammability Hazards Associated with the Use of Butane Gas Mixtures in BaBar

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The Stanford Linear Accelerator Center (SLAC) has designed a new detector (BaBar) for use at the accelerator center. Isobutane in combination with other gasses will be used in two areas of the Detector, the Drift chamber and the RPC chamber. Since isobutane is a flammable gas, its use raises safety concerns for the facility. Isobutane has been proposed for use in the drift chamber in a 20% isobutane/80% helium mixture. The RPC chamber design calls for the use of mixtures of isobutane with argon and Halon 134a ($C_2H_2F_4$) ranging from 1% to 15% isobutane depending on safety and detection requirements. The isobutane mixtures for the RPC Chamber will contain 30% Halon 134a and the balance argon.

An analysis was performed to determine the flammability hazard associated with using isobutane as a component in the gas mixtures for both the Drift chamber and the RPC. This analysis examined 20% isobutane/80% helium mixtures for use in the drift chamber and a range of isobutane/30% Halon 134a/balance argon mixtures for use in the RPC chamber. Flammability data for butane/air/inert gas mixtures were obtained from Bulletin 627, Bureau of Mines by Zabetakis [1].

Figure A1 shows a flammability diagram for butane obtained from Zabetakis [1]. The diagram includes flammability limits for mixtures of butane and either carbon dioxide (CO_2) or nitrogen (N_2) in air. The stoichiometric line (C_{st}) passes through the flammability region. The point at which the stoichiometric line intersects the boundary of the flammability region is known as the stoichiometric limit (SL), which represents the most dilute stoichiometric mixture that will propagate a flame. Figure A2 shows a similar diagram for methane which includes helium as an inerting agent. As can be seen in the diagram, the flammability limits in helium are larger than in either CO_2 or N_2. This is due to the lower heat capacity of helium relative to N_2 and CO_2.

A similar diagram for pentane is shown in Figure A3. Note that the pentane diagram includes curves for several fluorine compounds in addition to those for N_2 and CO_2. As can be seen in this diagram, all of the fluorine compounds have narrower flammability limits as compared to N_2 or CO_2. This again is largely related to the higher heat capacities associated with these compounds when compared to CO_2, N_2, or Helium.

Since neither a helium diagram or a Halon 134a diagram was available for butane, it was necessary to construct these diagrams in order to performed the required safety analysis. A thermodynamic analysis, as described below, was used to determine the approximate location of these curves on the butane flammability diagram.

The flammability limits for mixtures of butane in either helium or Halon 134a/argon were determined based on adiabatic flame temperatures. Research has shown that adiabatic flame temperatures at the flammability limits are insensitive to the inert compounds (see Beyler [2] for a good review). Thus, for the purposes of this analysis, it was assumed that the adiabatic flame temperature of any butane/inert gas/air mixture was the same at the flammability limits regardless of the inert compound.

The adiabatic flame temperatures for a range of limit mixtures of butane/air with either N_2 or CO_2 as an inert gas were calculated. These calculations showed that rich limit flame temperatures were typically 1200K to 1300K and lean limit temperatures were 1600K to 1700K, as expected. Next, adiabatic flame temperatures were determined for a range of butane/helium/air mixtures and for butane/argon/C_2F_6/air mixtures. Perfluoroethane (C_2F_6) was used as a surrogate for Halon 134a in these calculations because thermodynamic data for Halon 134a were not available over the temperature range of interest. Since C_2F_6 is very similar to Halon 134a especially in heat capacity, its use should introduce little error in the analysis.

Those mixtures which gave adiabatic flame temperatures in the ranges identified for CO_2 or N_2 mixtures were used to construct limit diagrams for the two inert systems. It should be noted that for the butane/argon/C_2F_6/air mixtures, the amount of C_2F_6 prior to dilution with air was kept at 30% while the amount of argon was varied depending on the percent butane in the mixture. This was based on the design requirements for the RPC chamber which specify a 30% Halon 134a concentration in the mixture regardless of the butane concentration.

Figure A4 shows the flammability limit curve for butane/helium mixtures as determined by the procedure given above. As can be seen in the figure, the helium limit curve lies outside the nitrogen limit curve. This is to be expected based on the methane results shown in Figure A2 and the fact that helium has a lower heat capacity than N_2.

Figure A5 shows a similar flammability limit curve determined for the butane/C_2F_6/argon/air mixtures. As can be seen in the diagram, this curve lies between the N_2 and CO_2 limit curves. This result is expected based on the fact that the argon/C_2F_6 mixture heat capacity lies between those of N_2 and CO_2. Once these limit curves were established, an analysis of the flammability hazard associated with the chamber mixtures was performed, as discussed below.

Line A on Figure A4 shows the range of mixtures of butane/helium/air that can be obtained by diluting a 20% butane/80% helium mixture with air. Point B on line A represents a 50% butane-helium/50% air mixture. As can be seen, this mixture is outside the rich flammable limit and thus cannot burn as a premixed flame. The point where line A crosses the upper flammable limit line for helium (point C) is the first mixture which becomes flammable. This mixture contains about 6% butane and corresponds to approximately a 3 to 1 dilution of the butane-helium mixture with air. Further dilution by air will result in a flammable mixture until point D (where line A crosses the lean limit). This point corresponds to about 1.8% butane in the mixture and a dilution of the original butane-helium mixture by approximately 11 to 1 with air. Beyond this point, any further dilution with air would produce a mixture outside the lean flammable limit and thus incapable of burning.

The range of premixed flammable mixtures identified above would apply to either the case of air leaking into the Drift Chamber containing the butane-helium mixture or to a leak of the butane-helium mixture into the area outside the chamber, once it was well mixed with air. However, because the percent butane in the original butane-helium mixture is above the rich limit, any leak out of the chamber could result in a diffusion flame supported by the butane fuel. Such a jet flame could have the potential to act as an ignition source for other fuels or to damage nearby equipment by the heat generated from the flame.

The four lines shown in the lower part of Figure A5 correspond to the range of mixtures obtained from different initial butane-argon-halon 134a mixtures. The numbers given at the right of each line denote the initial butane concentration in each mixture. As can be seen from the figure, the 1% and 4% butane mixtures never cross any of the flammability limit diagrams including the one for helium. Thus, these mixtures are not capable of burning either as premixed or diffusion flames. The third line indicates the initial butane concentration (approximately 6.5%) in a mixture with argon/Halon 134a which results in a marginally flammable mixture. This mixture touches the flammability limit line at a butane concentration of about 2.2% corresponding to a 3 to 1 dilution of the original mixture by air. The final line shows the range of mixtures obtained from a 15% initial butane concentration in argon/Halon 134a. As the figure clearly shows, this mixture is initially outside the rich flammable limit and result in a range of mixtures within the flammable limits. Thus, this initial butane/argon/Halon 134a mixture could produce either a diffusion flame or a premixed flame.

Based on the above analysis and envoking a 50 percent safety factor, mixtures of isobutane/argon/Halon 134a containing up to 4% isobutane can be used in the RPC chamber without hazard of fire or explosion. Although the normal factor of safety for flammable gases is four (i.e., the mixture is maintained at 25% of the lean flammable limit (LFL)), a safety factor of 50 % should be sufficient in this case due to the accuracy of continuous monitoring and gas shutdown capabilities which will measure the gas constituents to ±0.1%. The use of flammable mixtures requires additional safeguards since these mixtures are capable of creating a detonation in the confined space of either chamber.

An interlock systems should be considered for the Drift chamber (and for the RPC chamber if it uses greater than 4% butane) which prevents filling of the chamber with the butane mixture until the chamber has been fully purged with inert gas. The purge should be monitor by measuring the oxygen concentration in the chamber. Purging of the chamber with inert gas should continue until the oxygen measurement consistently reads below 1%. Once this reading is obtained, the chamber can be filled with the butane mixture. Oxygen monitoring should also be used during operation of the chamber to warn of an air leak into the chamber which could produce a flammable condition.

If the area immediately outside either of these chambers is confined such that flammable vapors could accumulate, then each of these areas should be monitored with a flammable gas detector in order to protect against the development of an explosive atmosphere.

References

1.) Zabetakis, M. G., "Flammability Characteristics of Combustible Gases and Vapors," Bulletin 627, Bureau of Mines, U.S. Dept. of the Interior, 1965.

2.) Beyler, C. L., "Flammability Limits of Premixed and Diffusion Flames," Section 2, Chapter 9, *The SFPE Handbook of Fire Protection Engineering*, Second Edition, DiNenno et al., Eds., National Fire Protection Association, Quincy, MA, 1995.

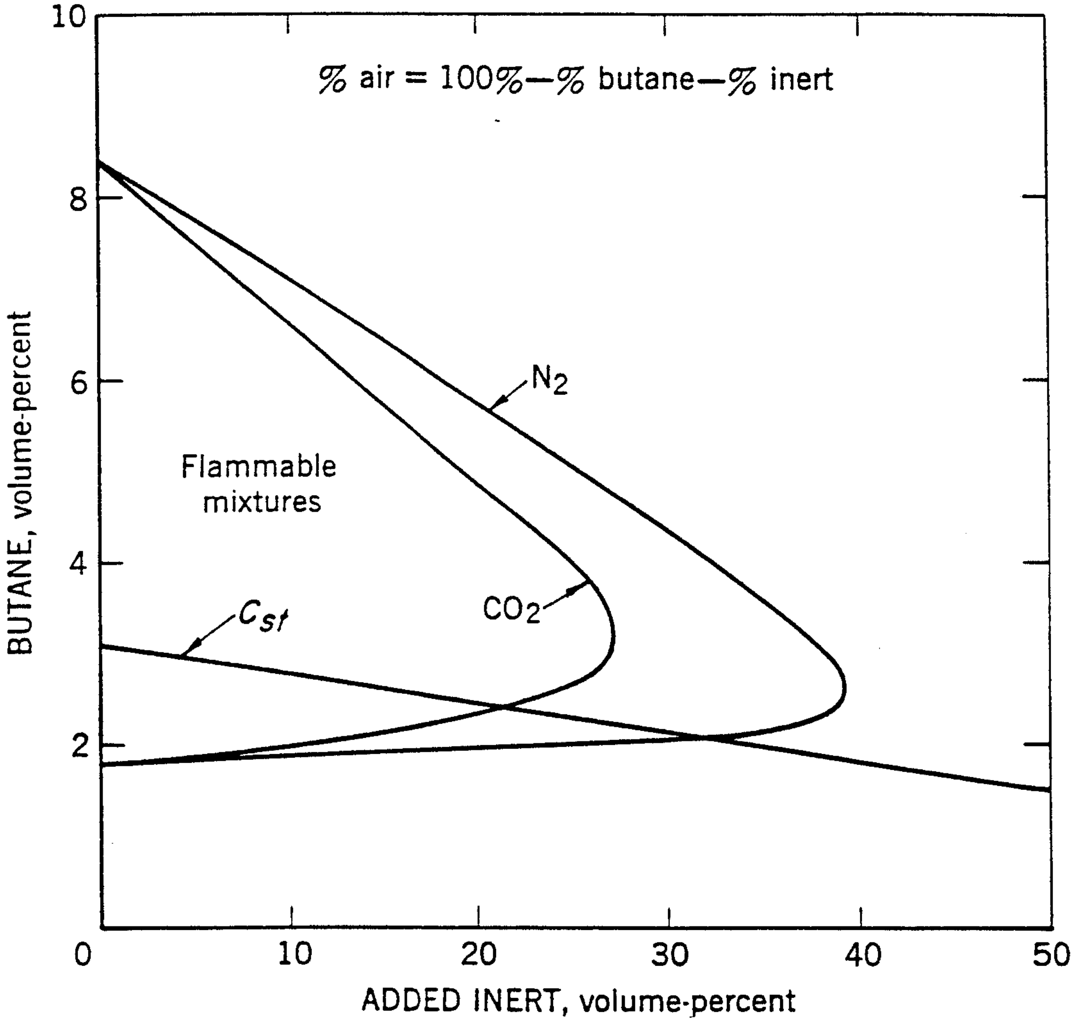

FIGURE 31.—Limits of Flammability of Butane-Carbon Dioxide-Air and Butane-Nitrogen-Air Mixtures at 25° C and Atmospheric Pressure.

Figure A1. Flammability Diagram for Butane from Zabetakis [1].

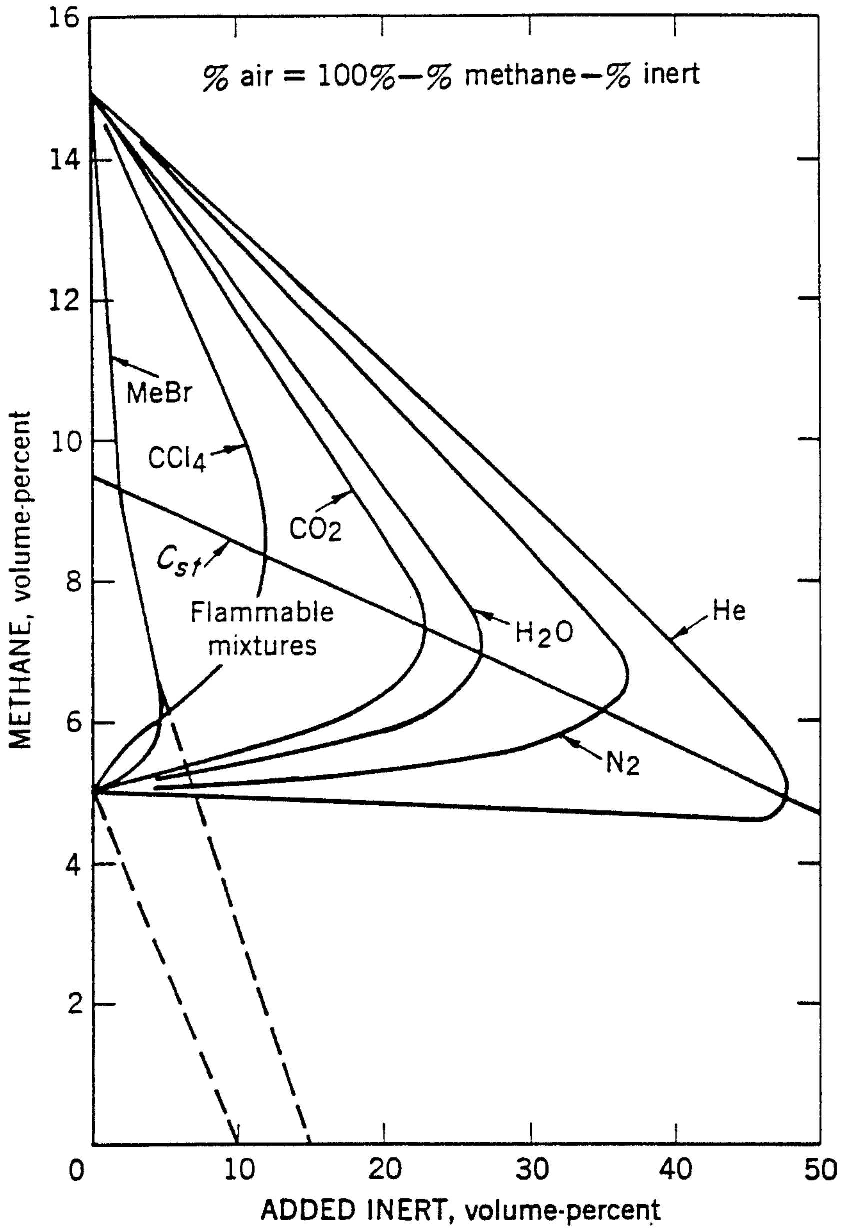

Figure 28.—Limits of Flammability of Various Methane-Inert Gas-Air Mixtures at 25° C and Atmospheric Pressure.

Figure A2. Flammability Diagram for Methane from Zabetakis [1].

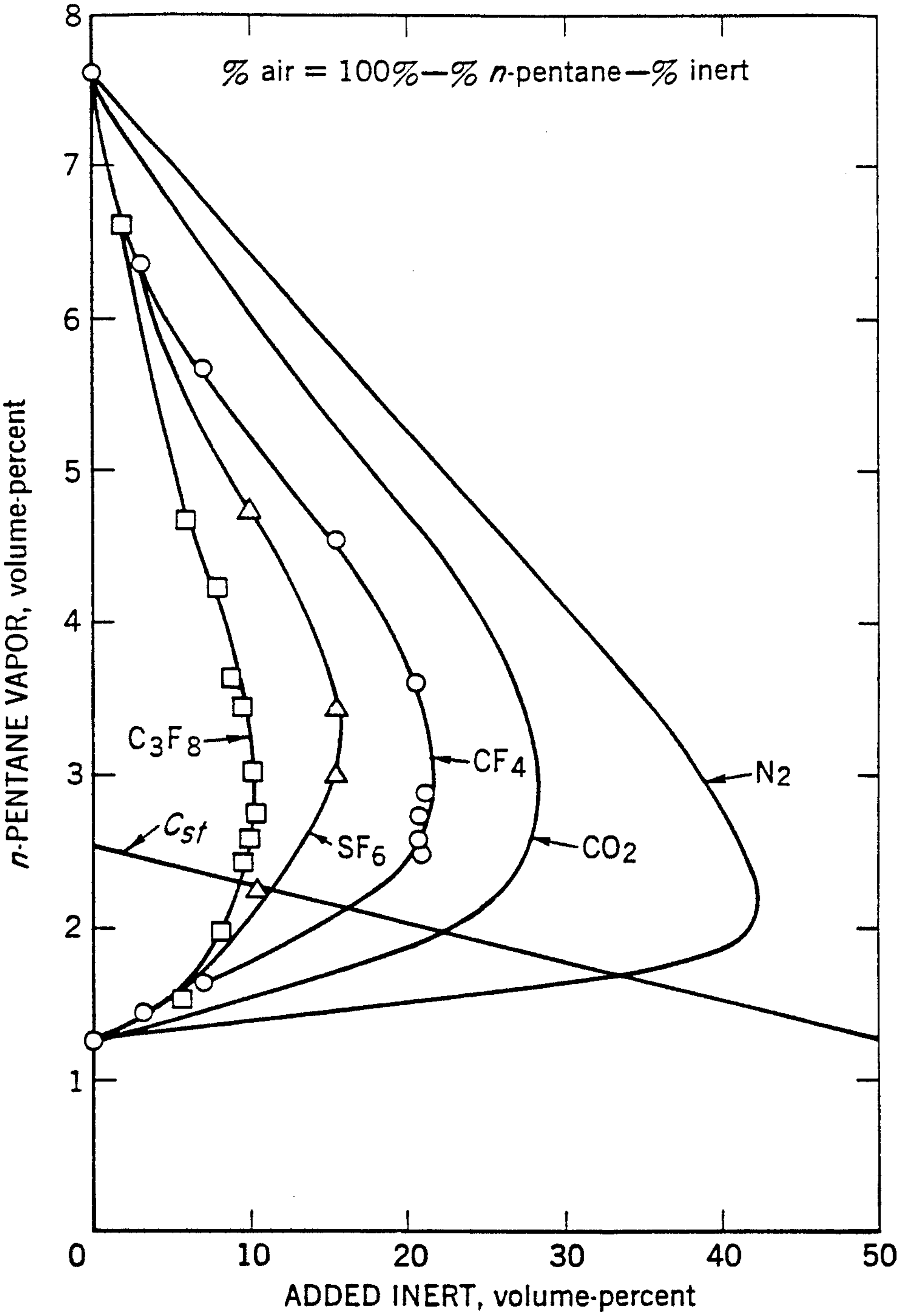

FIGURE 32.—Limits of Flammability of Various n-Pentane-Inert Gas-Air Mixtures at 25° C and Atmospheric Pressure.

Figure A3. Flammability Diagram for Propane from Zabetakis [1].

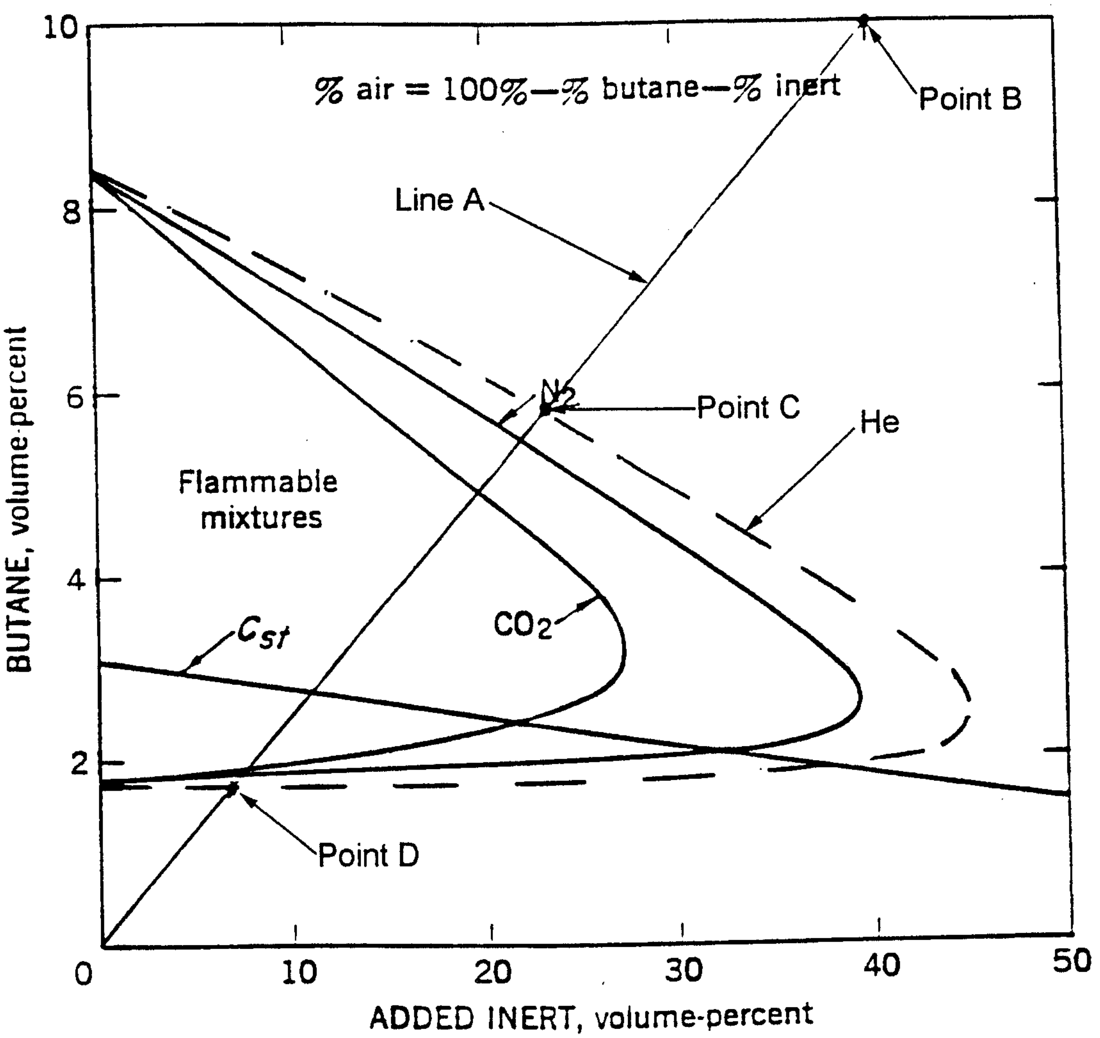

FIGURE 31.—Limits of Flammability of Butane-Carbon Dioxide-Air and Butane-Nitrogen-Air Mixtures at 25° C and Atmospheric Pressure.

Figure A4. Flammability Diagram for Butane with Helium Curve Added.

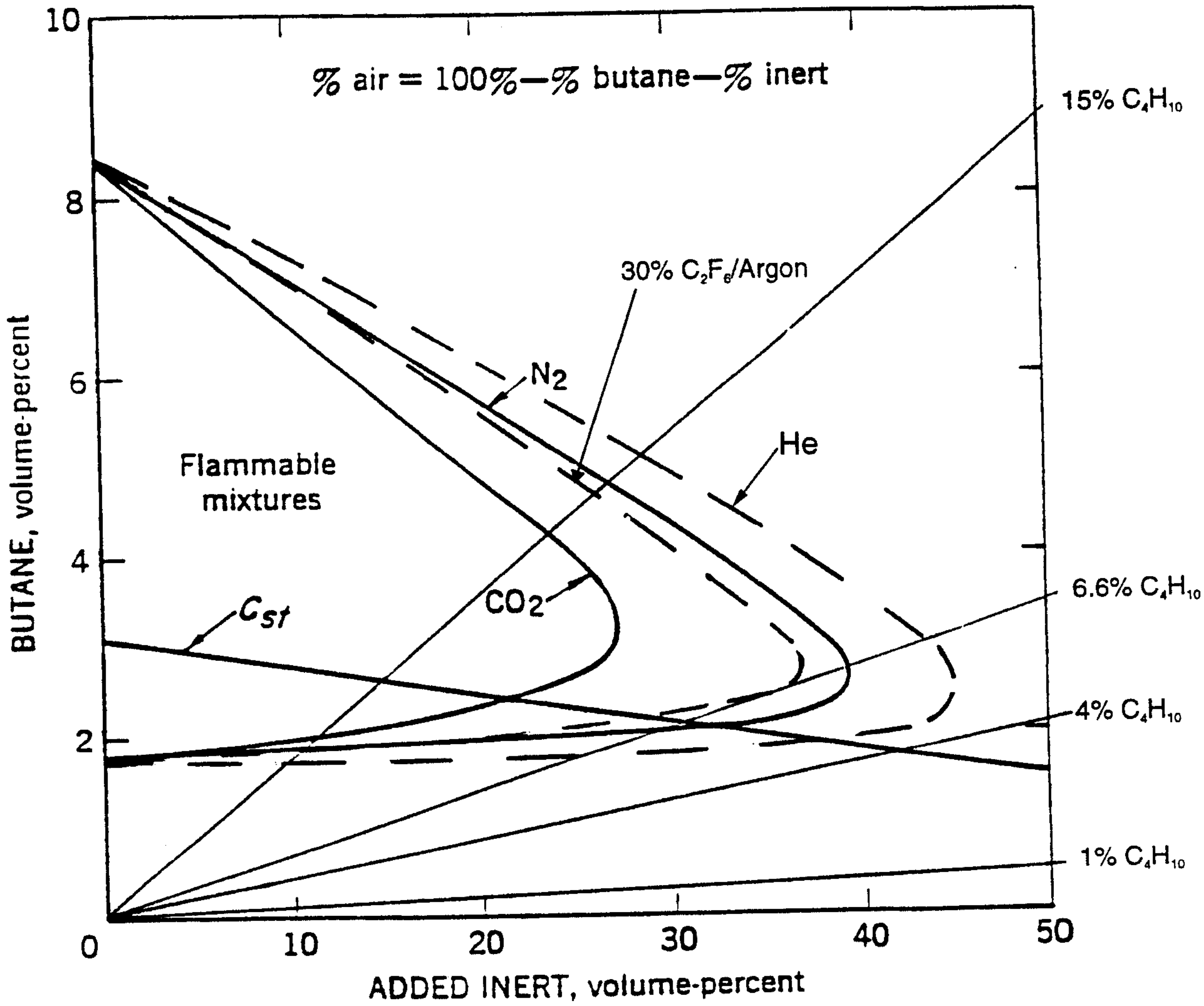

FIGURE 31.—Limits of Flammability of Butane-Carbon Dioxide-Air and Butane-Nitrogen-Air Mixtures at 25° C and Atmospheric Pressure.

Figure A5. Flammability Diagram for Butane with Argon/C_2F_6 Curve Added.