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Solid Propellant Gas Generators: An Overview and Their Application to Fire Suppression

Jiann C. Yang and William L. Grosshandler

Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, Maryland 20899 U.S.A.

ABSTRACT

A solid propellant gas generator is essentially an airbag inflator without a bag. That is, the gas generated is discharged directly into ambience rather than into a bag. A typical solid propellant gas generator consists of solid propellant tablets which will, upon ignition, rapidly react to generate gas-phase combustion products and particulates, an ignitor to initiate the combustion of the propellant, a filter system to prevent or minimize the release of the particulates from the combustion reactions into the ambience, a heat transfer mechanism (normally the filter itself) to cool the high temperature combustion gas before being discharged into the ambience, and an exhaust mechanism to disperse the gas efficiently. In this article, an overview of the current status on solid propellant gas generators will be discussed, and potential areas for future research will be suggested.

The solid propellant used in an airbag inflator typically contains sodium azide (NaN_3), iron oxide (Fe_2O_3), and small amount of other proprietary additives. The principle gas-phase product as the result of the combustion of the NaN_3/Fe_2O_3 propellant is nitrogen, and the resulting temperature is in the neighborhood of 1300 K. Solid species such as sodium oxide (Na_2O) and ferrous oxide (FeO) are also generated during the combustion process. Since the product gas is mainly nitrogen, the extension of airbag inflator technologies to suppress fires is ideal and logical. The suppression action of a solid propellant gas generator is believed to be due mainly to the effects of oxygen displacement (dilution) by nitrogen and gas discharge dynamics (flame stretch). To a lesser extent, a thermal effect also plays a role. However, the actual extinguishment mechanism(s) are not precisely known. It is possible that the extinguishment mechanism depends on the distance between the gas generator and the fire. If the location of the gas generator is very close to the fire, the extinguishment mechanism is likely to be attributable to blowing out the fire by the exhaust from the gas generator.

There are basically two types of airbag inflator systems: (1) the conventional and (2) the pre-pressurized or gas-assisted. In a conventional system, the gas that is used to inflate the bag depends entirely on the combustion gas generated by the solid propellant. However, in a pre-pressurized or gas-assisted system, the high temperature gas as a result of the combustion of the propellant is first mixed with a pre-pressurized inert gas at ambient temperature before being discharged into a bag. Similarly, one can also conveniently classify solid propellant gas generators into two categories, depending upon their functions: (1) conventional and (2) hybrid. When a gas generator is used alone for fire suppression, it is termed "conventional." When it is used together with other liquid or powdered fire suppressing agents, it is termed "hybrid." In a hybrid system, the gas generator normally is used as a means to provide sufficient pressurization so that the expulsion of liquid or powdered agent from a storage vessel can be facilitated.

A typical sequence of events that occurs during gas generation for fire suppression using solid propellants can be described as follows. Upon detection of a fire, the ignitor located in the combustion chamber of the solid propellant gas generator is activated. The ignitor, which contains a small amount of pyrotechnic materials (e.g., $Zr/KClO_4$), immediately releases high temperature gas and hot particulates *via* thermally initiated, exothermic chemical reactions of the pyrotechnic materials. The resulting temperature and pressure rises then initiate the solid propellant reactions near the ignitor, and a deflagration front rapidly propagates throughout the solid propellant bed. Very frequently, booster propellants, ignited by the ignitor, are used to facilitate the combustion of the main solid propellants. The high temperature and high pressure combustion gases, together with the condensed-phase products, then exit the combustion chamber through a filter before discharging into the ambience.

The attractiveness of using solid propellant gas generators in fire suppression applications lies in the fact that the system, when used alone, is considered to have no ozone depletion and global warming potential, and is physically very compact. Being a derivative from the airbag inflator technologies, there are voluminous research materials available in the literature. Another advantage is that since gases are generated *via* solid propellant reactions, the system can, in principle, be tailored to function over a period of few milliseconds (e.g., for aircraft dry bay fire protection) to few seconds (e.g., for aircraft engine nacelle applications) by manipulating the parameters that control the combustion mechanisms. In addition, the gas generators have very extended storage and service life. However, the toxicity of some of the by-products can not be ignored.

A review of previous research literature on airbag inflator technologies has suggested, through parallelism, the following areas for future research on solid propellant gas generators: (1) continuing search for better solid propellants, (2) better understanding of the suppression mechanism(s) of the product gases, (3) modeling and simulation of the thermochemistry and gas discharge dynamics, and (4) hardware optimization.

Sodium azide, which is used in the preparation of herbicides and in various organic syntheses, is the current principal chemical used in solid propellants for gas generators. Because of its potential health hazards (e.g., its potential to lower blood pressure), current research has been focused on the "non-azide based" propellants by the airbag manufacturers. The pertinent thermochemical and thermophysical properties to be considered for any new propellant should include (1) propellant thermochemistry (flame temperature and chemical composition of combustion products) and stoichiometry (moles of gas produced per mole of propellant burnt), (2) propellant ignitability and burning rates under various conditions, (3) toxicity of combustion products, (4) stability of propellent during storage and transport, and (5) propellant thermal properties. In addition, the grain size and shape of the propellant and how the propellant is packed in the gas generator also play important roles in the performance of the gas generator.

The suppression mechanisms of the combustion gases are the least understood because of the complexity of the gas discharge dynamics and turbulence interaction of the suppressants with the fires. Current practice for studying the suppression efficiency of the propellent, at least in the dry bay and engine nacelle applications, is to use trial and error to determine the amount of propellants required to put out a specific fire. A better understanding of the suppression mechanisms would therefore be needed in order to determine the required amount of propellants in a systematic way.

Current computer codes for simulating airbag inflator performance may be used with some modifications to evaluate the performance of gas generators. Note that existing computer codes address almost exclusively the simulation of internal performance of airbag inflators and that chemical equilibrium is assumed to determine the products of combustion and flame temperatures. Since the gas generation processes are extremely rapid and over in such a short duration, chemical equilibrium may not be reached, and simplified or detailed chemical kinetics should be considered in future code development. In addition, the interaction of the exhaust gas from the gas generator with the ambience has to be taken into account in the modified codes.

Current or future airbag inflator technologies can definitively benefit the hardware optimization of gas generators. Current active areas of research on airbag inflator hardware appear to be focused on the improvement of filter design and gas cooling system. For solid propellant gas generators, research should also be focused on how to disperse the gas effectively upon leaving the generator.

Presently, the gas generator technique has been proposed to be used in uninhabited areas because of the detrimental effects of oxygen depletion and nitrogen inerting on humans. Current interest has been focused on the application of the technique to aircraft dry bay and engine nacelle fires. Recently, tests performed at the Naval Air Warfare Center in China Lake, California and Wright Laboratories in Dayton, Ohio have demonstrated the feasibility of using solid propellant gas generators to suppress simulated aircraft dry bay fires. Other potential areas of application have also been suggested by the manufacturers. These include, to name a few, warehouse fire protection, industrial explosion prevention, and race car and shipboard engines.