FOCUS ARTICLE

Considerations for Investigating Combustible Dust Fires and Explosions

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Fires involving combustible particulate occur on a daily basis in the industrial sector. Explosions occur less frequently and may be relatively small events with little equipment damage and no personnel injury. In many cases, explosion events can cause significant property and equipment damage and result in injuries or even fatalities to personnel. The Chemical Safety Board has published reports on the subject and over a 36 year period a total of 392 incidents were reported that resulted in 185 fatalities and 1,055 injuries. It is likely that many events occurred during this period that did not result in injury to personnel and are not reported. The NFPA 652 Standard on Fundamentals of Combustible Dust requires that fire and explosion incidents be investigated and documented to include findings and recommendations. The standard also requires that a system be established to address and resolve the findings and recommendations and that this information be reviewed with affected personnel.

It is incumbent upon the owner/operator of the facility to perform a safe and systematic investigation of the event and prepare a thorough report that addresses the cause and origin and follow-up actions to prevent future occurrences. This focus article will provide valuable information with regard to conduct of the investigation and development of the follow-up report.

Conduct of Incident Investigations

Cause and origin investigations, involving combustible dust fires and explosions, typically conform to either the *Center for Chemical Process Safety (CCPS) Guidelines for Investigating Chemical Process Incidents* or *NFPA 921, the Guide for Fire and Explosion Investigations*. In either case, the goal is to thoroughly investigate the incident, collect and analyze the data, develop and test the hypotheses and establish the most probable cause and origin for the event. The goal of the investigation report is to establish root causes and causal factors and to provide recommendations to prevent future occurrences.

The scientific method is a principle of inquiry that forms the basis for legitimate scientific and engineering processes. It is applied using the steps shown in Figure 1. In situations where a final hypothesis, with regard to either cause or origin, cannot be confirmed with 100% reliability, the cause and/or origin is determined to be unknown. If this turns out to be the case then, based on considerations of availability of fuel, oxygen and a credible ignition source, probabilities can be assigned with regard to both cause and origin.

The scientific method requires that facts regarding the incident be collected by observation, experiment or other direct data gathering means. The collected data must also be analyzed before the formation of a hypothesis can take place. Analyzing the data is predicated on the knowledge, training, experience and expertise of the individuals performing the analysis.

Based on the data gathered and subsequent analysis, the investigation team produces a hypothesis or hypotheses to explain the phenomena whether it be the nature of fire or explosion spread, explosion forces, identification of the origin, secondary explosion events fire and explosion causes. Hypotheses shall be based solely on the empirical data that has been collected and developed into plausible explanations for the event.

The hypothesis is not valid unless it can withstand the test of scientific scrutiny. Testing of the hypothesis is accomplished using principles of deductive reasoning, where the investigation team compares the hypothesis to all known facts, as well as the scientific knowledge associated with phenomena relevant to the specific incident. The hypotheses can be tested either physically, by conducting experiments, or analytically by applying scientific principles in mental or modeling exercises.

If the hypotheses cannot be supported by the evidence, it is eliminated and alternate hypotheses are developed and tested. In this situation, collection of additional data or re-analysis of existing data may be required. The testing process needs to continue until all feasible hypotheses have been tested and one is determined to be uniquely consistent with the facts and principles of science. If none of the hypotheses can withstand an examination driven by deductive reasoning, the cause and/or origin is considered to be undetermined.

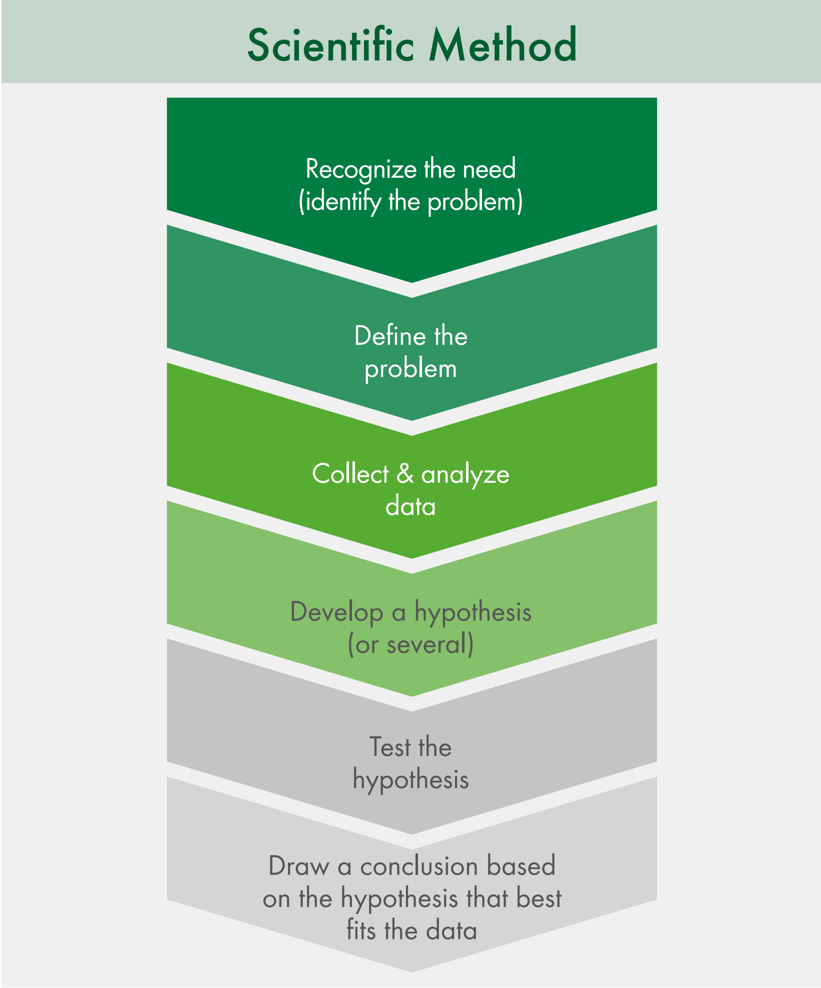

Figure 1 - Scientific Method Steps

Steps Involved in the Incident Investigation

There are a number of steps involved in the investigation of a combustible dust fire or explosion incident. The success of the investigation will be dependent on upfront planning, accurate documentation, the experience of the investigation team, the support of upper management and availability of the necessary resources.

Step 1 - Recognition of when an incident has occurred so that an incident investigation team can be activated. This might include recognizing a significant near miss (an event that could have resulted in a fire or explosion under different circumstances) that could benefit from investigation. Reporting the incident or near miss to the correct level of leadership needs to occur in a timely manner so the scene can be preserved, and important evidence secured for the investigation.

Step 2 - Assembling a qualified team that will determine and analyze the facts of the incident. The team is tasked with application of appropriate investigation tools and methodologies that will ultimately lead to identification of root causes and causal factors and the development of follow-up recommendations that could have prevented the incident or mitigated its consequences.

Step 3 - Gathering information, including interviewing personnel who have knowledge of the incident, documenting of the incident scene, including taking photographs, collection of evidence, analyzing data and development and testing of the hypotheses.

Step 4 - Determination of root causes and causal factors. A root cause is an initiating cause of a causal chain which leads to an outcome or effect of interest. Commonly, root cause is used to describe the depth in the causal chain where an intervention could reasonably be implemented to change performance and prevent an undesirable outcome. Examples of root causes include failure to perform a robust Process Hazard Analysis (PHA) that identifies, evaluates and controls hazards associated with the process, failure to develop and implement Standard Operating Procedures (SOPs) that include both normal and upset startup and shutdown procedures, lack of Training and inadequate Management of Change programs.

Causal factors are major unplanned, unintended contributors to an incident that, if eliminated, would have either prevented the occurrence of the incident, or reduced its severity or frequency.

Step 5 - Preparation of the investigation report which provides details regarding the circumstances surrounding the incidents, facts, findings and recommendations to prevent future occurrences.

Step 6 - Implement and communicate the team's conclusions. A critical task includes communicating the incident investigation team's conclusions to the affected parties.

Important Considerations for Combustible Dust Fire and Explosion Investigations

Some important considerations include, but are not limited to, the following:

> The incident scene must be secured, from a safety standpoint before it can be investigated. Preserve the scene to the greatest extent possible, since important evidence which could lead to development of cause and origin, may be lost if the scene is disturbed.

> In many cases, there is value added by bringing in an independent team that is not directly involved in the operation of the equipment or processes involved in the incident. An independent team that has no ownership of the equipment/process often provides a more objectified report with unbiased follow up recommendations.

> Interview eyewitness personnel as soon as possible after the incident, while their observations are still clear in their mind. It is a best practice to conduct interviews separately with these eyewitnesses.

> If the expectation is that the incident could lead to involvement of third parties, for example, insurance carriers or manufacturers of equipment/systems involved in the incident, notify these parties at the earliest possible time. If evidence is taken and tests are required to be conducted, third parties must have a right to participate in this exercise, otherwise any third party litigation may be compromised.

> Initial discussions with the incident investigation team and interviewees should include a discussion regarding any recent changes in the process that could have resulted in or contributed to the incident. This exercise may provide evidence that Management of Change procedures were not followed effectively.

> Avoid presumption of any potential cause or origin scenarios until data has been collected and a specific hypothesis can be rationally developed and tested.

> Investigations of explosions are usually more complicated when compared to the investigation of fires. In many cases, there are insidious hazards associated with the incident investigation including unstable structures and explosion debris which may contain toxic or otherwise hazardous combustible particulate solids. Analysis of fire patterns and force vectors can also lead to misleading results. A primary explosion incident may develop low overpressures, for the first ignited fuel, but can provide pressure waves to disturb dust accumulations in other areas of the building which can then be ignited producing higher pressures. Because of phenomenon like this, the determination of the cause and origin of the event can be extremely difficult and, in some cases, expert help may be required.

Summary

NFPA 652 the *Standard on Fundamentals of Combustible Dust* requires that incidents occurring in the industrial plant be investigated and documented to include findings and recommendations and that this information be reviewed with affected personnel. The CCPS *Guidelines for Investigating Chemical Process Incidents* and *NFPA 921 the Guide for Fire and Explosion Investigations* are the most popular documents used by incident investigation teams. This article has provided an overview of the scientific method and the various steps that are required as part of a combustible dust fire and explosion incident investigation. Important considerations are offered with respect to conduct of these investigations. In some cases, expert help may be needed to develop meaningful hypotheses regarding the cause and origin of these incidents. DEKRA Process Safety has extensive experience in the arena of process safety management and fire and explosion incident investigation and is available to provide such assistance, upon request.

References

> Chemical Safety Board Reports on Combustible Dust Explosions, www.csb.gov.
> Center for Chemical Process Safety, "Guidelines for Investigating Chemical Process Incidents", Third Edition, 2019, CCPS, AIChE, 3 Park Ave, New York, New York, 10016, 5991.
> NFPA 652 (2019) "Standard on the Fundamentals of Combustible Dust", Section 8.11.
> NFPA 921 (2017) "Guide for Fire and Explosion Investigations", Section 8.11.

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- Support the implementation, monitoring, and sustainability of PSM programs
- Audit existing PSM programs, comparing with best practices around the world
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- Energetic materials, explosives, propellants, pyrotechnics to DOT, UN, etc. protocols
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- Electrostatic testing for powders, liquids, process equipment, liners, shoes, FIBCs

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- Mechanical equipment ignition risk assessment
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