Review of Oxygen Reduction Systems for Warehouse Storage Applications

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Abstract

The basic principle of operation for an oxygen reduction (or hypoxic) system (ORS) is to displace the ambient oxygen in an enclosed environment with one or more nitrogen generators. The systems are used to reduce the occurrence of ignition and possibly to reduce the fire growth by means of a lower oxygen level in the ambient air. A number of test methods are used to define the appropriate oxygen level and the study did an evaluation of them through a NFPA research project, sponsored by the Fire Protection Research Foundation (FPRF) and its Property Insurance Research Group (PIRG).

The study consisted of a literature study and a research gap analysis for Oxygen Reduction Systems (ORS) in warehouses. For the purpose of this specific research project, oxygen reduction systems (ORS) for fire safety are defined as fire prevention systems, as compared with fire protection systems. The major focus area of the study has been, but not limited to, ignition prevention and associated test methods. Furthermore, reliability issues have been studied. The contents of the report apply to all ORS for fire, but the report does not address the efficacy of ORS in cases where ignition is not prevented and a fire develops in a reduced oxygen atmosphere

The study resulted in a set of research recommendations related to test methods, operations condition, fire service intervention and other areas such as health conditions. An important outcome of the study is that the actual determination methods in the design standards for ORSs are not covering all possible scenarios and it is important to decide if the system is used for fire prevention (i.e. preventing ignition) or fire protection (reducing fire growth). Further research such as validations studies and full-scale tests are needed. These will be investigated in a new follow up project.

Keywords: Hypoxic air, warehouses, oxygen reduction systems

Introduction

The primary purpose of oxygen reduction systems (ORS) for fire prevention applications is to create an environment of sufficiently low oxygen concentration to prevent, or significantly inhibit, fire initiation, development and spread. Currently, two major standards [1, 2] are used that provide guidance on design, installation and maintenance of ORS for fire. The Fire Protection Research Foundation (FPRF) identified issues with each of these standards that warranted further study especially for warehouses [3]. A small research project was commissioned to conduct a literature review, from which knowledge gaps and research needs could be identified. The following gives an overview of this study and indicates the research and development needs for ORS for warehouse storage applications. A complete overview and detailed description of the project can be found in reference [4].

Method and Approach

The study was conducted by performing the following tasks:

- Task 1: Determine System Objectives;
- Task 2: Impact on Hazard Conditions;
- Task 3: Determine Impact on Property Protection;
- Task 4: Gap Analysis.

In conducting the literature review for the first NFPA project, references are made to previous work that includes significant literature reviews. It was not the intent to repeat these works, but rather, to cite them for the reader and focus on more recent literature and on gaps as determined in prior and recent work. The bibliography in the NFPA report [4] provides an extensive list of sources of potential interests and the reader is referred to this report. The literature review in the NFPA project was conducted based solely on free, publicly available sources of publications and data. It is recognized that various institutional (e.g., insurance) or ‘for fee’ databases exist, which could have pertinent data. However, access to such databases was out of the scope of this effort.

For the purpose of the NFPA research project, oxygen reduction systems (ORS) for fire safety are defined as fire prevention systems, as compared with fire protection systems. As discussed in the report, the primary objective of fire prevention systems and strategies is to reduce the potential for ignition or sustained burning. The primary objective of fire protection systems, on the other hand, is to manage the impact of fire once sustained burning occurs by the means of reacting to the fire (e.g., through detection of the fire and then applying an extinguishing agent).

Identification of Research Gaps.

Based on outcomes from Tasks 1-3, a number of research and development gaps have been identified with respect to ORS used for fire prevention. A detailed description of the content of tasks 1-3 can be found in the NFPA report [4]. The research gaps are divided in four categories below: issues related to the test method used to determine the oxygen level concentration, issues associated with ORS in warehouse storage applications, issues associated with planned and emergency intervention in ORS and other related issues. The list below is an excerpt from the NFPA report [4], starting with the next paragraph.

Research/Development needs with respect to ORS test methods

The research in this report revealed that the test methods in EN 16750:2017 [1] and VdS 3527 [2,9] may not be sufficient to cover real-scale scenarios and may result in oxygen concentrations too high to prevent ignition in the real-scale scenarios. Even the newest version of VdS3527en from 2018 [9] does not change these conclusions. Therefore, research is needed on ORS test methods.

1. Data on real life scenarios with the systems are very limited and there should be research on the type of real-life scenarios such as in the work of Zhou et al. [6]. This study also suggests that EN 16750:2017 [1] and VdS 3527 [2,9] do not address reliability and maintenance issues to the required extent.

2. The actual test methods used in the standards are rather limited as described, and no full- or real-scale validation has been done. Therefore, the test methods might not be sufficient for all types of contents in case of warehouses and other alternatives should be studied.

3. The test method in the EN and VdS standards [1,2,9] have only one type of ignition source. This is not representative of reality. This type of ignition source is only one of the possible real-life ignition sources and international standardization documents such as ISO 11925 part 3 (ISO 1997) [5] lists a number of other flame ignitions sources. The goal of a test method should be to establish a sufficiently challenging ignition source or sources so that one can consider the occurrence of a more challenging ignition source as very remote. To address this, other ignition sources / strengths should be studied and incorporated into the test method.

4. As the test methods are mainly based on a small flame application, there is a need for the development of a test method or methods to investigate radiative and electrical high energy arc ignition sources. The methods need to have much clearer and detailed test methodologies and criteria than currently exist.

5. More data on ignition potential based on material type and storage arrangement for different O_2 concentrations would be beneficial. Ignition data is particularly needed for mixed fuels and especially for fuels that are packaged where oxygen is present in the packaging. The selection of the testing methodology used to collect additional ignition data should consider what material factors/attributes drive the oxygen concentration required to prevent ignition [6,7].

6. Further research on the required oxygen concentration is needed, i.e., what level should be used, for what fuels, in which applications, under what conditions. This is related to the performance objective in a fire safety design and guidance with the above-mentioned research.

Research/Development needs with respect to ORS operation and specific applications

1. Research into failure rates / reliability of ORS components is needed. Based on current research, data are lacking on critical components, such as compressors and sensors. This research may use existing reliability data for components.

2. There needs to be a failure mode analysis of ORS to determine appropriate industry standard Inspection, Test and Maintenance (ITM) programs as well as a failure analysis of the components in order to determine relevant requirements for listing of systems and components (required indications, alarms etc.).

   This should include identification of critical components that need to be in operating conditions and establish a requirement that the operating condition is visually indicated and easy to inspect. Guidance is needed on what is required to verify for the ORS on a regular basis, e.g., available production rate of nitrogen (compare to flow test of fire pump), testing of alarm signals (low oxygen, loss of power, high temperature on air compressors, etc.), and tightness of room. Maintaining the oxygen concentration over time when the building is starting to leak, the frequency of opening doors, and related factors need to be explored. Guidance on ITM intervals is needed. Guidance on back-up / emergency power requirement may also be needed as well as securing electrical power in terms of cable routing, breaker sizing etc. The standard UL 67377 [8] to some extent addresses this by requirements of functional safety for a system by means of performing a risk analysis and can be used as a starting point for the work.

3. There needs to be a failure mode analysis of ORS to determine potential reasons for impairments and associated needs to early detect such impairments. An operation safety management plan should be part of the guidance coming out of such research.

4. There needs to be a development of acceptance (compliance / commissioning) testing procedures for ORS.
5. There needs to be an industry-standard calculation method for ORS and required documentation for plan review as indicated in the main body of the report
6. Information should be gathered on operational costs for ORSs to aid in benefit-cost decisions.
7. There needs to be research into how leakages in warehouse storage buildings, particularly those targeted for ORS application, increase over time.
8. Research is needed to gain an understanding of whether tightness tests can be done for large volume spaces. While a door fan test is feasible for small enclosures such as IT server rooms (as would be for a gas extinguishing system), applicability of such a test to warehouses is highly questionable today.
9. ORS reliability and availability is important, and research on back-up system needs should be conducted.
10. Interaction of ORS and active fire protection, including smoke and heating venting systems, and sprinkler systems, would be beneficial.
11. The effect of moving a commodity into an ORS-protected space, that has been previously stored at ambient oxygen conditions, should be investigated. This is particularly true for porous materials which can absorb oxygen into void spaces, which will be released in the reduced oxygen environments.

Research/Development needs associated with planned & emergency interventions in ORS-protected spaces

Research is needed to better understand and assess / model manual firefighting interventions, such as smoke and heat venting, opening doors for firefighter access, etc., on ORS effectiveness and reliability.

Other Research/Development gaps / needs

While the focus of this work was related to the ORS as fire prevention system, it is clear from the literature study that the following areas, which were deemed outside of the scope of this study, would benefit from further research as well:

1. Level of oxygen acceptable with respect to medical conditions of people inside an ORS environment
    a. Lack of medical data is an open issue – more definitive testing / assessment by medical professionals would seem to be warranted to answer heath effect questions (see Annex A of the report [4]).

   b. Research appears to be needed not only on medical health, but also the ability of people to make the correct decisions in an oxygen-reduced environment.

2. Knowledge and data (e.g., experimental data) on the fire protection abilities of ORS, i.e., how much is fire spread reduced when an ignition occurs despite the reduced oxygen level.
   a. More data on burning rates and HRR based on material and storage arrangement, in different O_2 concentrations, would be helpful to further quantify the system benefit if the ignition threshold level is not met due to malfunction or impairment of the system.
   b. Damage criteria to be studied and defined. [end of excerpt, ref 4]

Conclusions

This study contained a literature study and a research gap analysis for ORS for warehouse storage applications. The major focus area of the study has been ignition prevention and the way how test methods are selected. Additionally, reliability issues have been studied. In order to be clear this means that the report is considering only the efficacy of ORS in case where one wants to prevent ignition. It does not take up those cases where ignition is not prevented and a fire grows in a reduced oxygen atmosphere. A general outcome of the project is that more research is need to study prevention of further ignition or controlling/extinguishing fire in environments with reduced oxygen concentrations. Safety of people in reduced oxygen atmospheres, without protection, has also not been addressed

This research revealed clearly that the test methods in EN 16750:2017 and VdS 3527 may not be sufficient to cover all real-scale scenarios and that considerable research is needed to further develop the test methods through full-scale fire tests. Other ignition scenarios should also be investigated in real-scale and linked to small scale tests and they will be part of an extension of the project which started 2020.

Investigation into reliability of ORS for fire is highlighted since there is need for research on how to design robust systems which are easy to inspect and maintain. If the ORS does not work, this can cause serious fire spread and damage. Procedures need to be established to check the reliability and/or real-life data.

The study identified a large number of recommendations for further research with respect to ORS test methods, the ORS operation and its specific application, to planned and emergency interventions in ORS-protected spaces. A second phase of the project was initiated at the end of 2020 in order to address the issue of the test methods and to develop both prescriptive and performance-based design procedures to establish the correct oxygen level.

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