Design and Verification of a Robust Filter for Oxygen Service

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An incident on September 8, 2007 in a 6,000-psi oxygen distribution system at NASA White Sands Test Facility (WSTF) resulted in the burn-through of a filter in this system (figure 1). The filter is the combination of both the filter housing and the filter element; both were evaluated. An investigation determined the filter was constructed of materials that are flammable in oxygen at the operating conditions. One resulting recommendation was to ensure that filters for oxygen service are constructed of burn-resistant materials and are of a robust design. This recommendation initiated the design of a burn-resistant and robust filter for oxygen service based on upgrading an older design.

Fig. 1. *Image of burned filter.*

Design process

When a new component is used, either out of necessity or in the interest of improvement, the component's function must be adequately understood. Considerations made in the design of this filter included: pressure rating, material compatibility, collapse pressure, flow capacity, metal-to-metal sealing, manufacturability, and resistance to plugging.

Engineers took great care in selecting materials for this filter so the materials were not only compatible in an oxygen environment but also mechanically compatible with each other. To achieve the necessary mechanical strength and compatibility, a different filter element was needed. Sintered nickel filter media, used with success in similar applications, were chosen for this filter element. This sintered element provided both excellent burn resistance and a greater tolerance for clogging due to the continuous flow path along its length (figure 2). We contacted several vendors, and as one was able to supply the required filter element, this vendor (Mott Corporation, Farmington, Conn.) was chosen as a supplier for the entire element assembly and was consulted regarding the flow capacity and collapse rating of this element.

We chose Monel 400® for the body of this filter because it has been proven as a burn-resistant material in oxygen systems. This housing material would serve not only to contain the pressure, but also to contain any combustion event if one were to occur. While Monel 400® proved a good choice for compatibility, concerns regarding the mechanical properties (specifically galling resistance) prompted careful material and lubricant choices in the mating materials.

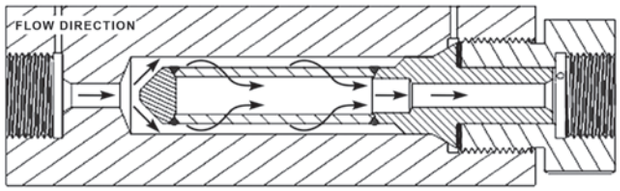

Fig. 2. *Cross section of filter.*

In high-pressure applications such as this component was designed for, polymeric seals create a vulnerability to oxygen fires. In this application, all seals within this component were metal-to-metal. The filter element itself also provided the seal between both the body and the outlet fitting. This feature resulted in the omission of a seal between the body and the outlet fitting, reducing the number of potential leak paths.

Particle impact is one of the primary ignition mechanisms in this type of component. Special care was taken in the design of this component to minimize the potential impact surfaces in the internal flow path.

Validation of design

In the development of a filter, validation of the design is as important as the design itself.

The filter design is based on several requirements, including the pressure rating, oxygen compatibility, and flow/filtering capability. The pressure rating is based on calculations per ASME [American Society of Mechanical Engineers] B31.3 code, and this code also requires each fabricated item to be pressure-tested. Generally this is a hydrostatic test to 150% of the design pressure. Oxygen compatibility is evaluated based on the configuration, pressure, and materials of construction. The flow/filtering capability is based on system requirements that are provided to the manufacturer.

A second, very important, design aspect of this component was the collapse rating of the filter element. Although the vendor provided an estimated collapse rating, we needed to establish this rating by testing. To collapse a filter element, the sintered media were coated with a high-quality household paint to fully plug the element. The element was then hydrostatically pressurized in the normal flow direction with the outlet of the filter open to ambient. A computer-controlled pressurization system was used to both control the pressurization rate and determine when the filter collapse occurred. Two filter elements were tested in this manner, and the lowest pressure at which collapse occurred was used to determine the collapse pressure rating for the filter. We used a factor of safety of 3 to determine the ratio between the pressure at which the element collapsed and the rated collapse pressure.

Oxygen compatibility was the final aspect of the design considered during validation. While significant test data demonstrate excellent oxygen compatibility for the Monel 400® alloys and Nickel 200 (commercially pure nickel), particularly in relation to burn resistance, little data are available for Nickel 200 in a sintered media form. The primary mechanism for igniting the sintered nickel element in this filter is by kindling chain. Kindling chain occurs when materials, such as debris trapped within the filter, combust and propagate to other materials in intimate contact with the combusting material.

We submitted samples of Nickel 200 sintered media for Promoted Combustion Testing to assess its propensity to sustain combustion in a kindling chain event. This testing

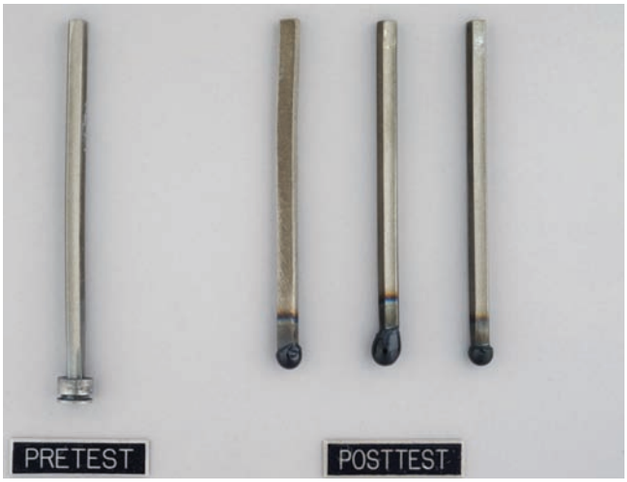

Fig. 3. *Tested samples pre- and posttest.*

is performed by initiating combustion of the test sample under pressure and monitoring its upward propagation. Increasing the test pressure helps us determine the threshold at which a given material will support combustion. Combustion in these Nickel 200 samples was not supported at pressures up to 10,000 psi, as seen in figure 3.

Other considerations

All filter elements must be cleaned at regular intervals. The length of these intervals, which is dependent on the use conditions, must be set short enough to avoid clogging and long enough to reduce maintenance costs. These intervals may also need to be adjusted over time based on the assessments performed at previous intervals. To better understand the maintenance requirements, we added a delta-pressure transducer to the pressure system to monitor the pressure drop across this component. In the event the delta-pressure exceeded pre-defined levels, this component would be removed and assessed. This transducer also provided a real-time assessment of the pressure system's health.

We also considered the specific process for cleaning these sintered elements. Unlike traditional mesh filter elements, sintered elements contain a high percent of entrapment areas due to the construction of the sintered media. These entrapment areas raise concerns for both entrapment of cleaning solutions and particulate. We therefore defined special procedures for cleaning these elements. Precautions such as the direction of flush, protection of the outlet side from contamination, and extend purges with elevated temperature bake-out were implemented to mitigate, or at a minimum reduce, concerns for entrapment.

Summary

Although it is often desirable to use commercial off-the-shelf hardware, there is occasion to design special components when system requirements eliminate off-the-shelf hardware from use. If designed correctly, these components can significantly improve the performance and/or robustness of a system. It is important in the design of these components to evaluate all issues relating to performance. In the case of this filter, we felt it was essential that a balance be found between mechanical function and oxygen compatibility.

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