



SAFE USE OF BRAZED ALUMINIUM HEAT EXCHANGERS FOR PRODUCING PRESSURIZED OXYGEN

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PREFACE

As part of a programme of harmonisation of industry standards, the Compressed Gas Association (CGA) has published CGA G-4.9, *Safe Use of Brazed Aluminum Heat Exchangers for Producing Pressurized Oxygen*, jointly produced by members of the International Harmonisation Council.

This publication is intended as an international harmonised standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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Amendments to 145/18

Section	Change
4.2	Several changes to the definitions
5	New title
6	New title
7	New title
8	New title
9	New title
10	New title
11	New title
Fig.3	New figure
Table 1	Updated
Table 2	Updated

Note: Technical changes from the previous edition are underlined

1 Introduction

Since the 1990s, a process for producing pressurized oxygen has become the industry standard. In this process, liquid oxygen is extracted from the separation column, pumped to higher pressure, and boiled in a heat exchanger to directly provide the elevated pressure gaseous oxygen product. Another method still being used for producing pressurized oxygen is to remove the oxygen as a gaseous product from the separation column, warm the gaseous oxygen to ambient temperature, and then raise its pressure with a gaseous oxygen compressor.

Brazed aluminum heat exchangers (BAHXs) are normally used as oxygen product vaporizers. Their use creates substantial contact between high pressure oxygen (both as liquid oxygen and gaseous oxygen) and aluminum material.

This publication reviews issues pertinent to the safe fabrication, installation, and operation of BAHXs used for boiling oxygen to dryness at elevated pressures.

A substantial portion of this publication is based on EIGA Doc 144, *Safe Use of Aluminum-Structured Packing for Oxygen Distillation* [1].¹ Questions initially raised for aluminum packing were extended later by analogy to BAHXs used as product oxygen vaporizers. Therefore, a significant amount of information from EIGA is incorporated into this publication in Sections 7, 8, 10, and 11 [1].

2 Scope

This publication addresses BAHXs used for boiling product oxygen at elevated pressures. The oxygen enters the BAHX as a subcooled liquid (or supercritical fluid) and leaves as a superheated vapor. Other BAHX uses in oxygen applications are not addressed, although incidents involving aluminum in oxygen service are discussed.

This publication contains a summary of current knowledge and industrial practices used in the safe application of BAHXs for the boiling of oxygen at elevated pressures.

This publication is based upon the combined experimental work, operating experience, and design practices of major producers and operators of air separation plants.

3 Summary

The industrial gas industry has used aluminum components extensively in oxygen service for many decades. This has included piping, heat exchangers, vaporizers, pressure vessels, distillation trays, and packing. Overall, the safety record of aluminum in oxygen service has been very good. BAHXs have been used in cryogenic air separation service since 1950.

The information assembled for this publication provides the background to conclude that the use of BAHXs for the production of pressurized oxygen can be safely practiced. In particular, this process reduces the possibility of hydrocarbon accumulation in the main reboiler/condenser when there is a high liquid withdrawal rate from the reboiler sump.

With respect to the use of BAHXs for elevated pressure product oxygen boiling, there has been one reported combustion incident.

The experimental work (Section 10) on the flammability of BAHX samples has shown that they are flammable in boiling oxygen (10.3) and can combust with considerable intensity; however, combustion can be arrested or inhibited by fluids in alternate passages under conditions normally encountered in elevated pressure product oxygen boiling applications. Condensed or cold supercritical inert fluid or air in BAHX alternate passages is more effective than gaseous inert fluid or air from the standpoint of combustion inhibition (10.4 and 10.5). However, there are some locations in the BAHX where liquid oxygen is present and the alternate passages contain either two-phase fluid or vapor only. This is most likely in locations where the oxygen vapor fraction is high.

¹ References are shown by bracketed numbers and are listed in order of appearance in the reference section.

The safe use of aluminum-fabricated equipment in oxygen service primarily depends on excluding ignition mechanisms, including the accumulation of flammable contaminants. BAHXs also use this philosophy.

The procedures that have resulted in this record of safe operation with aluminum components have included following the practices described in EIGA, *Guideline for Safe Practices for Cryogenic Air Separation Plants*, and proper cleaning of aluminum equipment according to standards such as EIGA, *Cleaning of Equipment for Oxygen Service*; ASTM G93, *Standard Guide for Cleanliness Levels and Cleaning Methods for Materials and Equipment Used in Oxygen-Enriched Environments* [2, 3, 4]. EIGA, *Safe Operation of Reboilers/Condensers in Air Separation Units*, offers additional insights pertinent to aluminum components in air separation plants [5].

For air separation plants containing BAHXs for elevated pressure product oxygen boiling applications, continued adherence to the practices in EIGA Doc 147 and following the cleaning specifications given in Section 11 of this publication are recommended to ensure safe use [2].

The use of adsorption purification units, which prevent acetylene and other undesirable hydrocarbons from entering the plant and initiating reactions, is strongly recommended when boiling liquid oxygen at elevated pressures in a BAHX.

In summary, the information assembled in this publication supports the safe use of BAHXs in oxygen boiling applications as an alternative to oxygen compressors. Test data were obtained at pressures up to 15 000 kPa (2180 psi)² using BAHX specimens. From current understanding, there is no step change in the risk of aluminum ignition and the combustion-propagation severity when increasing the pressure. Current industry references are up to 8 700 kPa (1260 psi). Designers of plants operating at high pressure should perform a risk analysis to confirm that any risks related to high oxygen pressure are addressed including the margin to mechanical design limits.

4 Definitions

For the purpose of this publication, the following definitions apply.

4.1 Publication terminology

4.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

4.1.2 Should

Indicates that a procedure is recommended.

4.1.3 May

Indicates that the procedure is optional.

4.1.4 Will

Is used only to indicate the future, not a degree of requirement.

4.1.5 Can

Indicates a possibility or ability.

² psi, bar, and kPa shall indicate gauge pressure unless otherwise noted as (psia; bar, abs; and kPa, abs) for absolute pressure or (psid; bar, dif; and kPa, dif) for differential pressure. All kPa values are rounded off per CGA P-11, *Guideline for Metric Practice in the Compressed Gas Industry* [6].

4.2 Technical definitions

4.2.1 Brazed aluminum heat exchanger (BAHX)

Brazed aluminum block as described in Section 5.

4.2.2 BAHX block sample

Small segment cut from the internal heat transfer fin-parting sheet section of a BAHX ranging in weight from 170 g to 400 g.

4.2.3 BAHX specimen

Small heat exchanger with segregated passages for two streams, at least one of which has a header, ranging in weight from approximately 3000 g to 13 000 g.

NOTE—A 3000 g BAHX uses approximately 1000 g of thin aluminum fins and parting sheets, while a 13 000 g BAHX uses 5000 g of fin and parting sheet stock.

4.2.4 Dead end boiling

Condition that occurs when heat is added to a pool or puddle of liquid to which liquid is continually added and from which only vapor is removed.

4.2.5 Prepurification unit (PPU)

System of vessels containing adsorbents used to remove contaminants from the air before distillation.

NOTE—These units are also called molecular sieve adsorbers, front-end purifiers, adsorption prepurification units (PPUs), and adsorption front ends.

4.2.6 Sealed cavities

Small volume that is completely sealed by metal and weld.

4.2.7 Supercritical fluid

Pure component or mixture of components that is at a pressure greater than its critical pressure.

NOTE—Although it can be argued that such a fluid is a compressed liquid if its temperature is less than the critical temperature of the fluid, the term supercritical fluid is used whether the fluid is greater or less than its critical temperature.

4.2.8 Violent energy release (VER)

Experimental result in which the following indications were observed during the combustion of aluminum in oxygen: a loud noise, white light, and physical destruction or substantial deformation of the specimen and/or the test vessel.

5 Description of brazed aluminum heat exchanger (BAHX) ³

5.1 Introduction

A BAHX consists of a block (core) of alternating layers (passages) of corrugated fins. The layers are separated from each other by parting sheets and sealed along the edges by means of side bars, and are provided with inlet and outlet ports for the streams. The block is bounded by cap sheets at the top and bottom.

³ Reproduced from *The Standards of the Brazed Aluminium Plate-fin Heat Exchange Manufacturers' Association* (ALPEMA standard) with permission [8].

An illustration of a multistream heat exchanger is shown in Figure 1.

The stacked assembly is brazed in a vacuum furnace to become a rigid core. To complete the heat exchanger, headers with nozzles are welded to the side bars and parting sheets across the ports.

5.2 Components of an exchanger

Figure 2 illustrates the components of an exchanger. The components are numbered for identification.

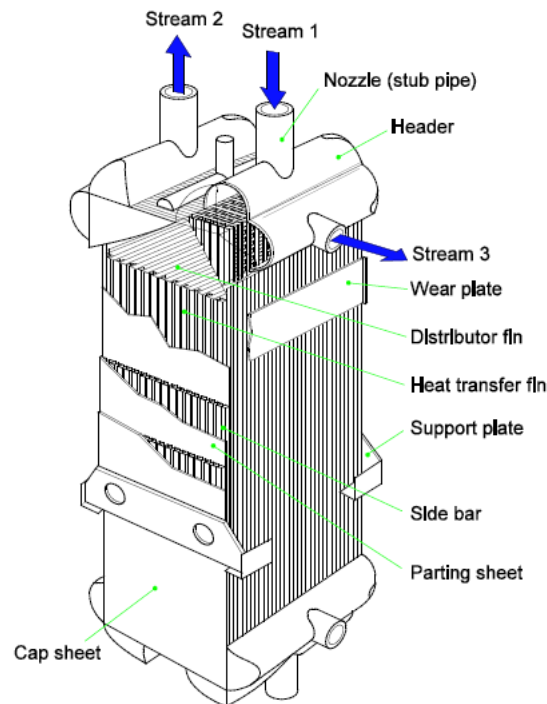


Figure 1 - Illustration of a typical multi-stream brazed aluminium plate-fin heat exchanger

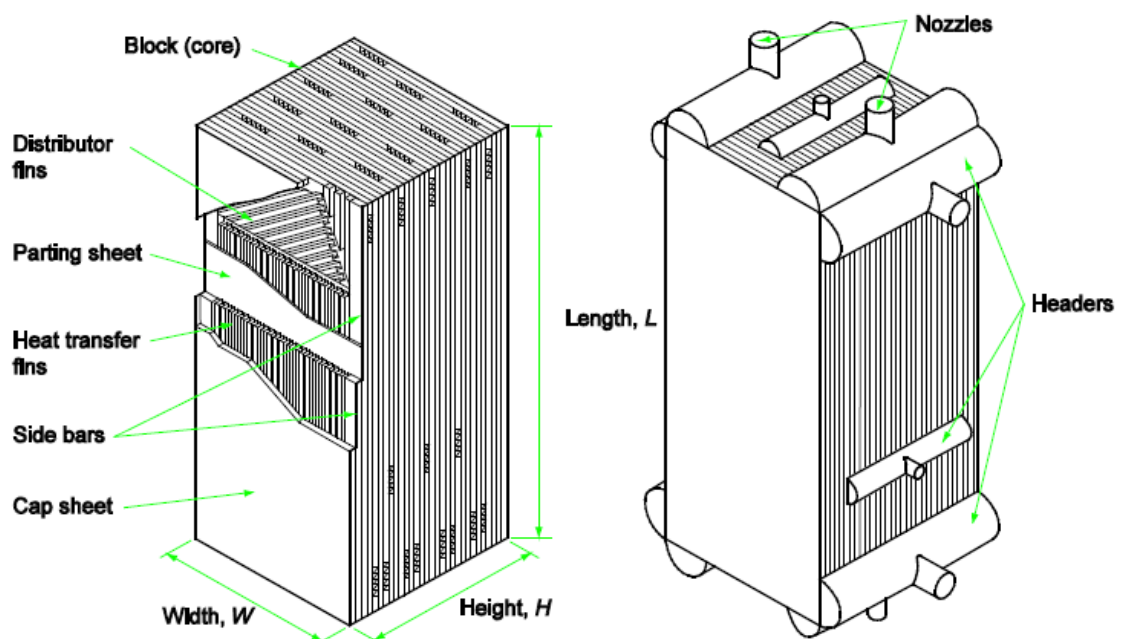


Figure 2—Components of a brazed aluminium plate-fin heat exchanger

5.3 Components of manifolded exchangers

Multiple BAHXs can be connected in parallel, in series, or in parallel-series combination to form one assembly.

Figure 3 illustrates an assembly of three BAHXs connected in parallel. In this case, each individual stream enters the assembly through a manifold, is distributed to the inlet nozzles on each of the three heat exchangers, flows through the heat exchanger, and leaves the assembly through the outlet manifold.

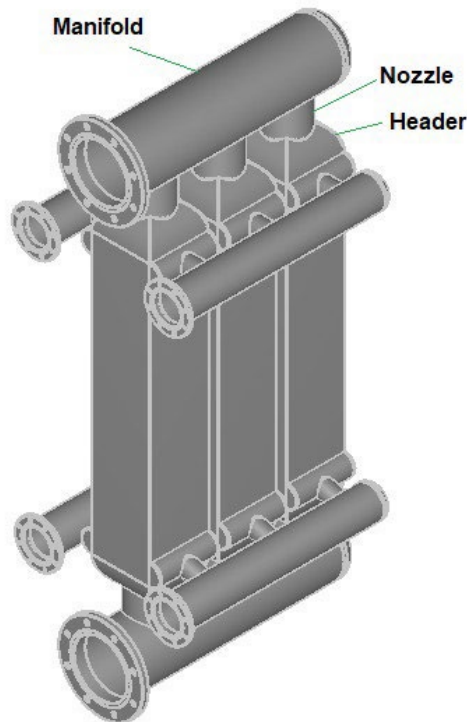


Figure 3—Typical assembly of three brazed aluminium plate-fin heat exchangers in parallel

6 Literature survey

Several papers are pertinent to the flammability of BAHXs for use in oxygen boiling services. A critical review of aluminum flammability data is presented by Werley, et al. [8]. Results of promoted ignition-combustion tests in oxygen-enriched atmospheres of various light metal alloys including aluminum are presented by Zawierucha, McIlroy, and Million [9]. Kirzinger, Bauer, and Lassmann and Pedley, et al., report on oil films on oxygen equipment [10, 11].

Specific to the use of BAHXs for boiling oxygen are the experiments described by Zawierucha and Million and by McNamara, et al. [12, 13, 14].

An investigation of the interaction between molten/burning aluminum and liquid oxygen is found in Barthélémy and Muller [15]. In a later investigation, Barthélémy, Roy, and Mazloumian reported the results of impact tests of aluminum in liquid oxygen and the effects of contaminants on impact behavior [16]. Other work investigates the effect of liquid oxygen purity on the probability of ignition by impact of contaminated aluminum [17].

The preparation of this publication and the general knowledge of aluminum-liquid oxygen reactions has been enhanced by a number of investigations related to the safe use of aluminum-structured packing in air separation plants. These investigations have involved flammability tests of aluminum packing, comparisons with sieve trays, studies of ignition mechanisms, and oil migration. Key investigations in these areas are those of Mench, et al.; Kirzinger and Lassmann; Dunbobbin, Hansel, and Werley; Zawierucha, et al.; Lassmann and Kirzinger; Barthélémy; Egoshi, Kawkami, and Fujita; and Fano, Barthélémy, and Lehman [18, 19, 20, 21, 22, 23, 24, 25, 26, 27].

In addition to BAHXs, pumps are a key component of pumped liquid oxygen systems. Known compatibility tests pertinent to this component involving aluminum and liquid oxygen are those of Bauer, et al. [28, 29].

Several significant incidents involving aluminum and liquid oxygen have appeared in the literature. An accident investigation involving the explosion of a liquid oxygen tank truck was reported on in a National Traffic Safety Board (NTSB) Report [30]. An aluminum-liquid oxygen reaction involving a submerged pump was reported by Kilmartin [31]. Van Hardeveld, et al. and Lehman et. al reported on explosions in air separation units (ASUs) [32, 33].

Of potential significance in aluminum-liquid oxygen reactions are trace contaminants. Lassmann reported on the enrichment of hydrocarbons in pressurized liquid oxygen evaporators [34]. Miller, et al. discussed the solubility of nitrous oxide and carbon dioxide in air separation liquids [35]. Trace contaminant behavior in ASUs was investigated by Meneses, et al. [36]. Lassmann and Meilinger reported on the adsorption of hydrocarbons on solid carbon dioxide and nitrous oxide in liquid oxygen at ambient pressure [37]. McKinley and Himmelberger give the upper and lower flammability limits of hydrocarbons in gaseous oxygen and mention that the liquid oxygen flammability range is narrower than seen in gaseous oxygen [38].

In air separation plants and associated systems there are a number of components handling both gaseous oxygen and liquid oxygen such as compressors, piping, tankage, and heat exchangers. Organizations such as the American Society for Testing and Materials (ASTM), CGA, European Industrial Gases Association (EIGA), and National Fire Protection Association (NFPA) have prepared standards or technical bulletins pertinent to such components [39, 40, 41, 42, 43, 44, 45].

7 Industry survey on incidents of aluminum-oxygen combustion and oxygen compressor comparison

7.1 Background

Since the 1950s, when aluminum replaced copper as the preferred material of construction of cryogenic equipment, aluminum and oxygen have reacted on several occasions with varying degrees of intensity. The configuration of the aluminum involved in these reactions has varied from the very thin foil used in superinsulation to heavy plate stock that is rolled and used for elevated pressure vessels in storage tanks or liquid oxygen trailers.

Evidence of both molten aluminum and aluminum oxide can be used to determine whether or not aluminum participated in a reaction. Whereas molten aluminum might or might not be indicative of an aluminum-oxygen reaction, aluminum oxide is always indicative of this reaction.

Hydrocarbon-liquid oxygen reactions in the presence of aluminum can be divided into three categories:

- Cases of violent hydrocarbon combustion in aluminum equipment without the actual participation of the aluminum in the reaction;
- Cases in which there was evidence that a very small amount of aluminum had burned before the reaction was arrested. This has occurred in both reboilers and sealed cavities; and
- Cases where serious incidents occurred in plants involving aluminum-oxygen combustion. These were initiated by accumulated combustibles in the reboiler/condenser and resulted in extensive combustion of the aluminum reboiler. Aluminum packing was also burned in two cases as a consequence of the reboiler incidents [1, 32, 33].

A wide distribution of hydrocarbon contamination in the equipment is a probable factor for the propagation of aluminum combustion [16]. Where the contamination is localized, the high thermal conductivity of aluminum can help arrest propagation. Other factors influencing propagation are discussed in 7.4 and 7.5.

There have also been incidents in sealed cavities where the aluminum has participated but the reaction did not propagate.

The elimination of designs with sealed cavities has reduced the number of incidents. This design improvement prevents hydrocarbon accumulation and high pressure oxygen buildup.