CGA H-10—2012

COMBUSTION SAFETY FOR STEAM REFORMER OPERATION

FIRST EDITION

COMPRESSED GAS ASSOCIATION, INC.

PREFACE

Recognizing the need for a standard on combustion safety for steam reformer operation, the Compressed Gas Association (CGA), with the participation of the European Industrial Gases Association (EIGA), has produced H-10—2012, *Combustion Safety for Steam Reformer Operation*. This standard is intended as a joint EIGA/CGA international harmonized standard for the use and application of all members of EIGA and CGA worldwide. This standard has been reviewed and fully endorsed by CGA's HYCO Committee and Standards Council.

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1 Introduction

Large scale hydrogen production has been practiced for decades and the demand for such production has grown over that period. In the last several years, developments in crude oil processing, such as the increased use of hydrogen to remove sulfur and the refinement of heavier crude oil stocks, has driven significant growth in the demand for hydrogen supply.

In response to this demand, industrial gas companies operate and maintain large scale hydrogen production facilities worldwide and have done so with an exemplary safety record for many years. However, it should be noted that large scale hydrogen production involves potential personnel and process safety hazards that must be addressed in design and operation. Such hazard potential is inherent to the processing of toxic and flammable gases via high temperature reforming as practiced in hydrogen production.

The steam reformer represents the core operating unit of most large scale hydrogen production facilities. Therefore, steam reformer furnace combustion safety is fundamental to the overall safe operation of these large scale hydrogen plants. This publication provides best practices for managing the combustion safety aspects of steam reformer operations. The associated potential safety hazards include fire, rapid uncontrolled energy release, gas release, as well as personnel exposure related to such hazards.

There are some internationally accepted standards that apply to the combustion systems of process furnaces. Such standards, including NFPA 86, *Standard for Ovens and Furnaces*, EN 746, *Industrial thermoprocessing equipment*, Parts 1-3, and API RP 556, *Instrumentation, Control, and Protective Systems for Gas Fired Heaters,* some of which are not specific to reforming furnaces, provide guidance on combustion safety systems [1, 2, 3]. These standards and other standards referenced in this publication shall be consulted when considering combustion safety for steam reformers.

It should be noted that there are other industries, such as ammonia and methanol production, that operate large steam reformers. Therefore it may be instructive to consider the learning and experiences from those industries through organizations such as the American Institute of Chemical Engineering: Ammonia Safety Symposium and the International Methanol Producers and Consumers Association (IMPCA).

Steam reformer furnace design will continue to develop along with methods to implement combustion safety in these furnaces. A wide variety of steam reformer designs, configurations, and component equipment exists today. Therefore, this publication included some generalized statements and recommendations on matters on which there may be diversity of opinion or practice. Users of this publication should recognize that it is presented with the understanding that it can supplement, but not take the place of, sound engineering judgment, training and experience. It does not constitute, and should not be construed to be, a code or rules or regulations [4].

2 Scope and purpose

2.1 Scope

This publication applies to steam reformers that are operated with natural gas, refinery off-gas, naphtha, and other light hydrocarbon streams. It specifically applies to large volume hydrogen production plants, defined for this publication as a production capability of 373,000 scfh (10 000 Nm^3/hr) (9 MMSCFD or 241,000 Nm^3D) or greater.

This publication covers operation, maintenance, and certain design aspects of steam reformers relative to the potential safety hazards of the combustion process inherent to these units. Emphasis is placed on operational guidance and features that provide safeguards against such hazards such as furnace control philosophies, safety interlocks, and inspection routines. The publication is not intended to address the details of design, installation, and construction of steam reformers.

2.2 Purpose

The purpose of this publication is to inform and guide interested parties on the procedures and practices fundamental to combustion safety in the operation of steam reformers. This publication presents a baseline for safe reformer operation which, if followed, assures our customers that the hydrogen they receive from member companies has been produced according to accepted industry-wide safety guidelines.

3 Definitions

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

3.1 Air change
Quantity of air, provided through the burners, equal to the volume of the furnace and the convection section.

3.2 Air/Fuel ratio
Ratio of combustion air flow rate to the fuel flow rate typically expressed as a molar ratio.

3.3 Alarm
Audible or visible signal indicating an abnormal or potentially critical condition.

3.4 Autoignition temperature (AIT)
Minimum temperature required to initiate self-sustained combustion of a solid, liquid, or gas in air.

3.5 Boiler
Closed vessel in which water is heated and steam is generated by heat input from combustible fuels in a self-contained or attached furnace.

3.6 Burner
Device for the introduction of fuel and air into a combustion chamber at the velocity, turbulence, and concentration required to maintain ignition and combustion of fuel.

3.7 Burner management system (BMS)
Control system dedicated to combustion safety and operator assistance in the starting and stopping of fuel preparation and combustion equipment and for preventing misoperation of and damage to fuel preparation and combustion equipment.

3.8 Casing
Metal plate used to enclose the fired heater.

3.9 Combustion air
Air used to react with the fuel in the combustion process.

3.10 Control element
Component of a safety instrumented system that implements the physical action necessary to achieve a safe state. Examples include valves, switch gear, motors, etc., including their auxiliary elements.

3.11 Convection section
Portion of the reformer, downstream of the furnace, where flue gas passes over heat exchangers and heat transfer occurs via radiation and convection.

3.12 Damper
Valve or plate for controlling draft or the flow of gases, including air.

3.13 Double block and bleed (DB&B)
Piping or instrument arrangement that combines two block (or isolation) valves in series with a vent valve in between the block valves as a means of releasing pressure between the block valves with the intent to provide positive isolation.

3.14 Draft
Negative pressure (vacuum) measured at any point in the furnace, typically expressed in inches of water column (mm of water column).

3.15 Duct
Conduit for air or flue gas flow.

3.16 Excess air
Air supplied for combustion in excess of theoretical air. Frequently expressed as a percentage above stoichiometric requirements (e.g., 10% excess air or 110% of stoichiometric).

3.17 Excess oxygen
Flue gas oxygen measurement, typically on a wet gas basis (e.g., 1.5% excess oxygen approximately corresponds to 10% excess air, depending on fuel composition).

3.18 Explosive mixture
Flammable or combustible mixture in a confined space.

3.19 Explosion vent
Vent designed to relieve explosion pressures resulting from ignition of a mixture of combustible gases and air.

3.20 Feed-forward control
Signal used to anticipate a change in the measured variable.

3.21 Flame
Body or stream of gaseous material involved in the combustion process and emitting radiant energy at specific wavelength bands determined by the combustion chemistry of the fuel. In most cases, some portion of the emitted radiant energy is visible to the human eye.

3.22 Flame detector
Device that senses the presence or absence of flame and provides a usable signal.

3.23 Flue gas
Gaseous products of combustion including the excess air.

3.24 Forced draft (FD) fan
Device used to pressurize and supply ambient air to the combustion chamber to support combustion.

3.25 Furnace
Portion of the reformer where the combustion process takes place.

3.26 Hazard and operability study (HAZOP)
Structured and systematic examination of a planned or existing process or operation in order to identify and evaluate problems that can represent risks to personnel or equipment, or prevent efficient operation.

3.27 Induced draft (ID) fan
Device used to remove the products of combustion from the reformer furnace by introducing a negative pressure differential.

3.28 Interlock
Device or an arrangement of devices, in which the operation of one part or one mechanism of the device or arrangement controls the operation of another part of another mechanism.

3.29 Levels of protection analysis (LOPA)
Method to assess the number and types of protection layers (e.g., engineered protection features or systems) needed to provide an adequate safeguard against a specified hazard or risk in an industrial process.

3.30 Light hydrocarbons
Compounds consisting of hydrogen and carbon with low molecular weights, such as methane, ethane, propane and butane.

3.31 Logic system
Decision-making and translation elements that provide outputs in a particular sequence in response to external inputs and internal logic and are comprised of the following:

– hardwired systems—individual devices and interconnecting wiring;

– microprocessor-based systems;

– computer hardware, power supplies, I/O devices, and the interconnections among them; and

– operating system and logic software.

3.32 Low fire (minimum fire)
Minimum fire rate that results in stable combustion.

3.33 Monitor
To sense and indicate a condition without initiating automatic corrective action.

3.34 Overfiring
Combustion of fuel and air in excess of amount required for the reforming reaction that could cause damage to equipment or surrounding areas, and/or injury to personnel.

3.35 Permissive
Condition to meet before a piece of equipment can be operated or a step in a sequence can be completed. After the equipment is operated or sequence step is completed the permissive is ignored.

3.36 Pressure swing adsorption (PSA)
Multiple fixed bed gas purification process that uses materials that selectively adsorb one or more gas species from a mixture. Regeneration of the adsorbent is accomplished with a pressure reduction or swing.

3.37 Purge
Flow of air or an inert medium at a rate that will effectively remove any gaseous or suspended combustibles and replace them with the purging medium.

3.38 Radiant section
Portion of the furnace in which the heat is transferred to the tubes, primarily by radiation.

3.39 Refinery off-gas
Gas stream removed as a by-product or purge from various crude oil processing units; typically consisting of a mixture of hydrogen, olefins, and alkanes.

3.40 Safety instrumented function (SIF)
Function implemented by a safety instrumented system (SIS) that is intended to achieve or maintain a safe state for the process and/or personnel regarding a specific hazardous event.

3.41 Safety instrumented system (SIS)
Independent system composed of sensors, logic solvers, and final elements designed for the purpose of:

– automatically taking an industrial process to a safe state when specified conditions are met; and/or

– permitting a process to move forward in a safe manner when specified conditions allow (permissive functions).

3.42 Safety integrity level (SIL)
Relative measure of the reliability of a safety-instrumented system and/or function as described in industry standards as either an average probability of failure to function on demand or as a risk reduction factor.

3.43 Steam reformer
Processing unit where steam is reacted with hydrocarbons over a catalyst at high temperatures to produce hydrogen and carbon oxides. The reformer includes a furnace/radiant section and a convection section.

3.44 Tail gas
Low pressure contaminant rich rejection stream from pressure swing adsorption.

3.45 Wet basis
Gas stream composition including water versus dry basis where water is excluded.

4 Fundamentals of combustion safety

4.1 Combustion fundamentals

Oxygen (air), fuel and an ignition source are required for combustion to occur. Combustion reactions involving organic compounds and oxygen take place according to stoichiometric combustion principles.

Stoichiometric oxygen requirements for combustion of a fuel can be determined from the balanced chemical reaction equations.

Based on the stoichiometric reactions below, the air requirement is calculated by including excess margin over the stoichiometry.

Ideal combustion reactions that can occur in a reformer furnace include:

– Hydrocarbon gas: $C_nH_m + (n + m/4)O_2 \rightarrow nCO_2 + \left(\frac{m}{2}\right)H_2O$

– Carbon monoxide: $2CO + O_2 \rightarrow 2CO_2$

– Hydrogen: $2H_2 + O_2 \rightarrow 2H_2O$

Complete combustion occurs when all of the fuel is burned. Air is the source of oxygen (21% by mole or volume). Usually 8% to 10% excess air is required for complete combustion to occur and for optimum operation.

4.2 Basic combustion hazards

Basic combustion hazards that should be considered include flame instability, flame lift off, back burning, after burning, fuel accumulation, and exposure to hot gases.

4.2.1 Flame instability

Flame instability can occur when fuel pressure or fuel mixing in the burner is insufficient, fuel composition deviates too strongly from design, or if flue gas is not evenly distributed in the furnace. Flame instabilities can lead to incomplete combustion, severe furnace pulsation or flame impingement that can damage the equipment in the furnace (e.g., tubes, refractory, etc.)

4.2.2 Flame lift off

When the reformer draft or fuel pressure is too high (compared to the burner design parameters), a lift off of the flame from the burner tip(s) can occur. Depending on the operating status of the furnace it could produce the following results:

– flame is extinguished and creates the potential for uncombusted fuel to accumulate in the furnace; or

– burner is reignited if the gas is above the autoignition temperature (AIT) and can cause severe pulsation and potential damage in the furnace.

4.2.3 Back burning

Back burning can occur if the fuel pressure drops in the fuel line below the burner design parameters. This enables a combustible mixture or the flame to travel from the burner tip up into the fuel supply in the line. This condition creates the potential for an unintended energy release.