A Hazard Analysis of a Gas-Fired GMH8 Goodman Furnace

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Abstract. A safety analysis of an industrial gas-fired furnace is presented. The analysis includes a discussion of prior injury data, a preliminary hazard analysis, a fault tree analysis, and a failure modes and effects analysis of the bench grinder. Based upon these various analyses, the most common and the most severe injury modes are identified, as well as the causes of these injury modes. Finally, in each analysis, specific preventive measures, including preventive maintenance is discussed.

Keywords: Product safety · Hazard analysis · System safety

1 Introduction

Gas furnaces are used in a variety of industries, such as make materials similar to ceramics and glass. The Goodman furnace is used to test samples of material at Collins Aerospace, where the first author is employed. The facility has a variety of gas furnaces, mostly nitrogen based, since Collins make brakes out of carbon fiber and the carbon must go through a series of baking. The furnaces used for actual production are much larger of course but they are similar to the Goodman furnaces we use for our research and development department. During the tenure of the first author working at Collins Aerospace, there haves not been any incidents with the furnaces, but the first author is aware incidents that happened in the past or that have happened at similar facilities. The Goodman furnaces can be very dangerous if not maintained and used properly. The Furnace Deck, the department at the facility with the furnaces, is the primary focus of attention as the furnaces are constantly being monitored.

The GMH8 Goodman furnace is a two stage, convertible, multi-speed, upflow/horizontal furnace. The overall assembly is shown in Fig. 1. One can see that the two-stage furnace has two separate compartments with two separate doors. There are different models of the GMH8 furnace, and the dimensions of the "A" and "B" vary by model. The GMH80453AN model A is 14 inches wide and GMH80453AN model B is 12.5 inches wide.

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Figure 2 shows all of the dimensions and specifications of the GMH80453AN model B furnace.

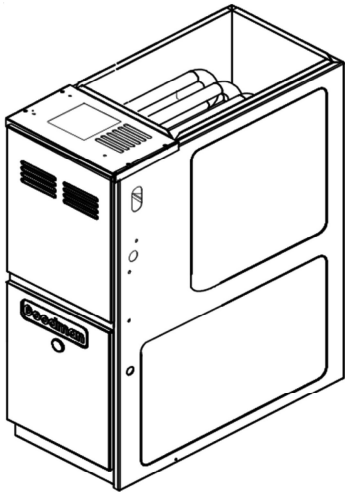

Fig. 1. The GMH8 Goodman furnace

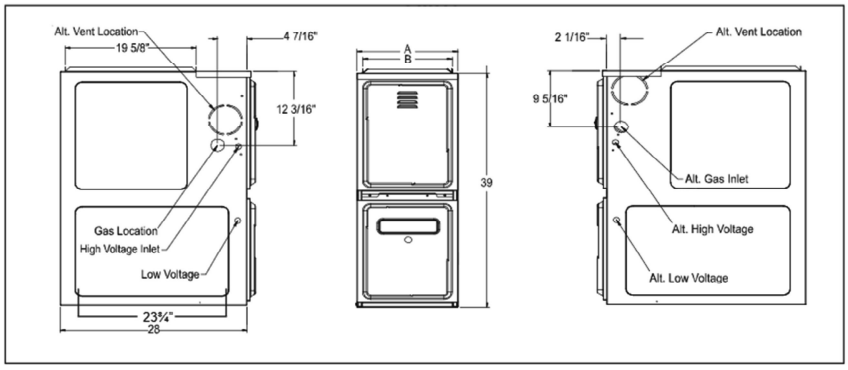

Fig. 2. Dimensions of the GMH80453AN model B furnace

The number of parts a product is made up of can also have an effect on the number of possible hazards. Gas furnaces have a variety of possible hazards such as the gas that is being burned to heat the furnace, and the ventilation that is required among others. Some of the hazards are addressed by warnings on the product as shown in Figs. 3 and 4.

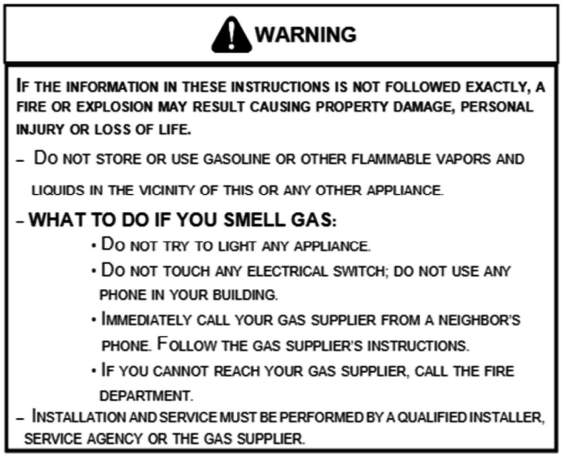

Fig. 3. Safety warnings

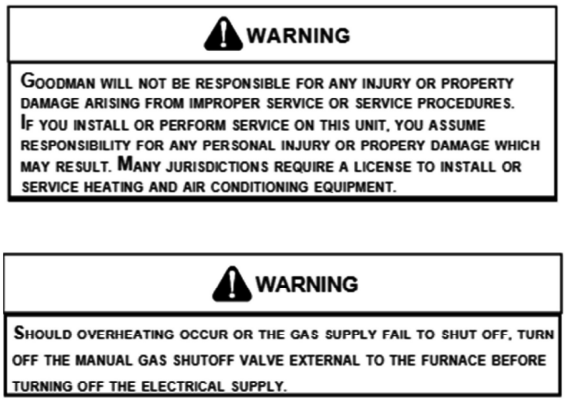

Fig. 4. More safety warnings

2 Accident History

As shown by the OSHA Accident database, this particular product can be very dangerous if safety precautions are not taken.[1] The most recent 40 entries for coded with the keyword "furnace" were analyzed. The 40 entries are shown in Table 1.

[1] OSHA Accident database. (https://www.osha.gov/pls/imis/AccidentSearch.search?acc_keyword=%22Furnace%22&keyword_list=on). Accessed on 12/5/18.

Table 1. OSHA accident database entries coded with the keyword "furnace".

#	Summary Nr	Event Date	Report ID	Event Description
1	104643.01	4/11/2018	418200	Employee Is Killed When Struck By Falling Furnace Door
2	104222.01	1/31/2018	355112	Employee Is Killed In Flash Fire After Using Gasoline To Sta
3	100975.01	11/15/2017	418300	Employee Is Setting Up Furnace And Suffers Multiple Burns To
4	100645.01	10/24/2017	111500	Employee Is Hospitalized After Exposure To Carbon Monoxide
5	100058.01	10/15/2017	523400	Employee Sustains Burns When Combustible Gas Ignites
6	99338.015	9/20/2017	751910	Two Employees Burned When Loader Cab Catches Fire And Explod
7	99339.015	9/20/2017	751910	Two Employees Burned When Loader Cab Catches Fire And Explod
8	98960.015	9/8/2017	522300	Employee Is Burned While Servicing Electric Arc Furnace
9	98855.015	9/3/2017	418300	Employee Trips And Receives Second Degree Burns On Feet From
10	99200.015	7/27/2017	552652	Employee Is Burned When Gas Ignites
11	101061.01	7/3/2017	751910	Employee Suffers Burns In Aluminum Explosion
12	101062.01	7/3/2017	751910	Employee Suffers Burns In Aluminum Explosion
13	96730.015	6/4/2017	751910	Employee Is Injured When Building Explodes From A Flammable
14	100464.01	5/4/2017	552652	Employee Sustains Burns From Flying Molten Metal When Scrap
15	95320.015	5/3/2017	522300	Employee'S Finger Tip Is Amputated While Closing A Furnace D
16	94340.015	3/24/2017	523400	Employee Catches Pants On Fire While Replacing Electrode And
17	100086.01	3/15/2017	950635	Employee Receives Electrical Shock/Burn From Induction Furna
18	93938.015	3/15/2017	112600	Employee Is Engulfed By Hot Ash And Suffers Multiple Burns
19	93710.015	3/7/2017	552652	Employee Is Struck And Killed By End Cap From Pressurized Do
20	93864.015	2/16/2017	1054191	Three Employees Suffer Carbon Monoxide Inhalation From Fault
#	Summary Nr	Event Date	Report ID	Event Description
21	92959.015	1/23/2017		Worker Is Struck By Falling Pipe Inside A Furnace And Sustai
22	92127.015	1/6/2017		Employee Is Injured In Furnace Explosion
23	78220.015	7/16/2015		Employee Falls And Suffers Unspecified Injuries And Is Kille
24	59829.015	3/31/2014		Employee Caught Between Metal Door And Conveyor Is Killed
25	57509.015	1/20/2014		Two Employees Are Killed By Electric Arc Furnace Explosion
26	56388.015	11/15/2013		Employee Is Lighting Furnace And Is Killed In Explosion
27	202654976	11/13/2013	3711	Three Employees Sustain Burns Opening Pressurized Chamber
28	201694924	11/8/2013	3339	Employee Amputates Fingers Between Pot And Furnace Frame
29	49267.015	7/29/2013		Employee Falls Into Furnace And Dies From Asphyxiation
30	48688.015	7/17/2013		Employee Is Severely Burned While Repairing Vent Stack And I
31	202637500	4/10/2013	3312	Employee Dies From Heart Attack At Blast Furnace
32	50126.015	4/7/2013		Employee Is Burned In Explosion And Fire, Later Dies
33	202531695	3/18/2013	3398	Employee Is Killed When Struck By Rack Of Cylinders
34	202637112	3/13/2013	3312	Three Employees Are Burned Due To Arc Flash/Heat
35	200535771	12/31/2012	3321	Employee'S Thumb Is Amputated While Replacing Furnace Lid
36	200452977	3/24/2012	3567	Employee Is Killed When Pinned Between Feeder/Charge Door
37	17215.015	2/23/2012		Three Employees Are Burned When Lp Gas Leaking Out Of A Cyli
38	200999142	2/3/2012	3341	Employee Is Killed When Crushed By Aerial Lift
39	202478129	1/21/2012	3398	Employee Is Burned After Falling Into Furnace
40	201392578	12/13/2011	3567	Employee Electrocuted By Faulty Plug Dies

Based upon these most recent forty entries in the database coded with the keyword "furnace", an analysis was performed examining how many fatalities were documented for each year and what causes the injury/fatalities. Figure 5 shows the number of fatalities that occurred each year from the most current entries back to 2012. The 2013 calendar year had the most, five fatalities.

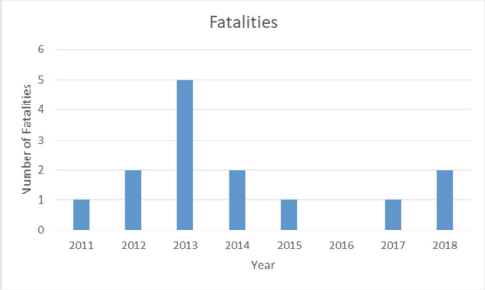

Fig. 5. Number of fatalities by year.

Figure 6 shows, using a pie chart with the percentage for each injury or fatality by cause. Looking at the chart one can see that most injuries are caused by explosions, followed by fires, and then being crushed by the furnace door. 22% of the time explosion is the cause of the injuries/fatalities, 15% of the time is caused by fires and 12% of the time is caused by the furnace door of lid falling or crushing the person.

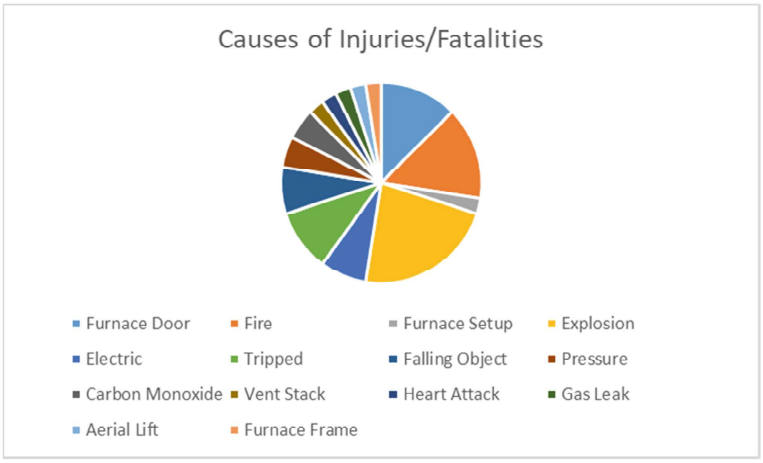

Fig. 6. Causes of injuries/fatalities

3 Preliminary Hazard Analysis

Given these data regarding the various causes of injuries and fatalities, a preliminary hazard analysis was then performed to further investigate these incidents and to identify hazard controls for the hazards. This PHA is shown in Table 2 below.

Table 2. Preliminary Hazard Analysis for gas furnaces.

Hazard	Cause	Effect	Corrective or preventative measures
Fire or spark ignites gas outside combustion chamber	Highly flammable nature of liquid fuels	The inside of the furnace cabinet will be on fire, a possibility that the fire can spread to the outside area of the furnace	A well-designed layout should be designed to fit the furnace and fire extinguishers should be near the area
Overheated electrical circuits	Electronics get overheated by the furnace	Potential of melted wires could lead to faulty equipment and possible dangerous area	Electronic material must be able to withstand the high temperatures
Burn injury from contacting hot surfaces	Outside of the furnace may be hot when furnace is running	The be hot to the touch causing burns	Have warnings on the outside of the furnace to avoid people from leaning on or coming in contact with the outer area of the furnace
Gas leak, resulting in incomplete combustion	Gas leakage is common in furnaces as time goes by	Can lead to carbon monoxide poisoning	Every so often, check for gas and oil leaks (should be part of PMs)

4 Fault Tree Analysis

A fault tree created focusing only on fires and explosions with gas furnaces though there is potential for other different hazards. The fault tree analysis is shown in Fig. 7. The Fault Tree shows the different possible causes that could lead to a fire and/or an explosion. The most common reasons are gas/oil leaks, overpressure, clogged ventilation, and ignoring signs such as alarms or warnings.

Some of the safety techniques that were found for the Goodman gas furnaces were done through the installation process in order to make sure that the equipment is in proper use from the start. Figure 8 shows the safety instructions from the manual.[2]

[2] GMH8 Installation Instructions. https://www.questargas.com/ForEmployees/qgcOperationsTraining/Furnaces/Goodman_GMH8-GDH8-DualSaver-Gas-Furnace-Installation-Instructions.pdf. Accessed on 12/5/18.

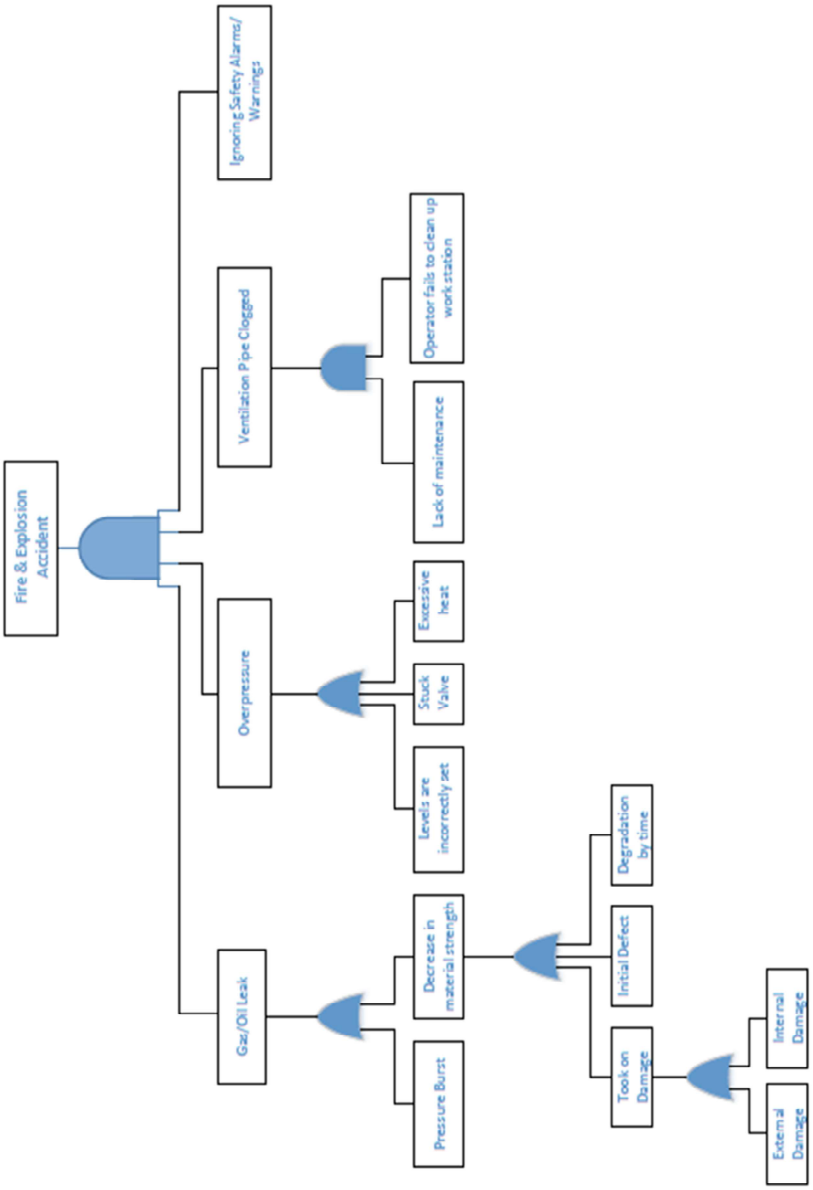

Fig. 7. Fire/explosion fault tree.

⚠ WARNING

TO PREVENT POSSIBLE PROPERTY DAMAGE, PERSONAL INJURY OR DEATH DUE TO ELECTRICAL SHOCK, THE FURNACE MUST BE LOCATED TO PROTECT THE ELECTRICAL COMPONENTS FROM WATER.

⚠ WARNING

HEATING UNIT SHOULD NOT BE UTILIZED WITHOUT REASONABLE, ROUTINE, INSPECTION, MAINTENANCE AND SUPERVISION. IF THE BUILDING IN WHICH ANY SUCH DEVICE IS LOCATED WILL BE VACANT, CARE SHOULD BE TAKEN THAT SUCH DEVICE IS ROUTINELY INSPECTED, MAINTAINED AND MONITORED. IN THE EVENT THAT THE BUILDING MAYBE EXPOSED TO FREEZING TEMPERATURES AND WILL BE VACANT, ALL WATER-BEARING PIPES SHOULD BE DRAINED, THE BUILDING SHOULD BE PROPERLY WINTERIZED, AND THE WATER SOURCE CLOSED. IN THE EVENT THAT THE BUILDING MAY BE EXPOSED TO FREEZING TEMPERATURES AND WILL BE VACANT, ANY HYDRONIC COIL UNITS SHOULD BE DRAINED AS WELL AND, IN SUCH CASE, ALTERNATIVE HEAT SOURCES SHOULD BE UTILIZED.

Additional Safety Considerations

- This furnace is approved for Category I Venting only.
- Provisions must be made for venting combustion products outdoors through a proper venting system. The length of flue pipe could be a limiting factor in locating the furnace.

Electrostatic Discharge (ESD) Precautions

NOTE: Discharge body's static electricity before touching unit. An electrostatic discharge can adversely affect electrical components.

Use the following precautions during furnace installation and servicing to protect the integrated control module from damage. By putting the furnace, the control, and the person at the same electrostatic potential, these steps will help avoid exposing the integrated control module to electrostatic discharge. This procedure is applicable to both installed and non-installed (ungrounded) furnaces.

1. Disconnect all power to the furnace. Do not touch the integrated control module or any wire connected to the control prior to discharging your body's electrostatic charge to ground.
2. Firmly touch a clean, unpainted, metal surface of the furnaces near the control. Any tools held in a person's hand during grounding will be discharged.
3. Service integrated control module or connecting wiring following the discharge process in step 2. Use caution not to recharge your body with static electricity; (i.e., do not move or shuffle your feet, do not touch ungrounded objects, etc.). If you come in contact with an ungrounded object, repeat step 2 before touching control or wires.
4. Discharge your body to ground before removing a new control from its container. Follow steps 1 through 3 if installing the control on a furnace. Return any old or new controls to their containers before touching any ungrounded object.

III. PRODUCT APPLICATION

This furnace is primarily designed for residential home-heating applications. It is NOT designed or certified for use in mobile homes, trailers or recreational vehicles. Neither is it designed or certified for outdoor applications. The furnace **must** be installed indoors (i.e., attic space, crawl space, or garage area provided the garage area is enclosed with an operating door).

This furnace can be used in the following non-industrial commercial applications:

Schools, Office buildings, Churches, Retail stores, Nursing homes, Hotels/motels, Common or office areas

In such applications , the furnace must be installed with the following stipulations:

- It must be installed per the installation instructions provided and per local and national codes.
- It must be installed indoors in a building constructed on site.
- It must be part of a ducted system and not used in a free air delivery application.
- It must not be used as a "make-up" air unit.
- All other warranty exclusions and restrictions apply.

This furnace may be used as a construction site heater **ONLY** if the following conditions are met:

- The vent system is permanently installed per these installation instructions.
- A room thermostat is used to control the furnace. Fixed jumpers that provide continuous heating CANNOT be used.
- Return air ducts are provided and sealed to the furnace.
- A return air temperature range between 60°F (16°C) and 80°F (27°C) is maintained.
- Air filters are installed in the system and maintained during construction, replaced as appropriate during construction, and upon completion of construction are replaced.
- The input rate and temperature rise are set per the furnace rating plate.
- 100% outside air is provided for combustion air requirements during construction. Temporary ducting can be used.
  NOTE: Do not connect the temporary duct directly to the furnace. The duct must be sized according to the instructions under *Section V, Combustion and Ventilation Air Requirements, Section 5.3.3.*
- The furnace heat exchanger, components, duct system, air filters and evaporator coils are thoroughly cleaned following final construction clean up.
- All furnace operating conditions (including ignition, input rate, temperature rise and venting) are verified according to these installation instructions.

NOTE: The Commonwealth of Massachusetts requires that the following additional requirements must also be met:

- Gas furnaces must be installed by a licensed plumber or gas fitter.
- A T-handle gas cock must be used.
- If the unit is to be installed in an attic, the passageway to and the service area around the unit must have flooring.

To ensure proper installation and operation, thoroughly read this manual for specifics pertaining to the installation and application of this product.

⚠ WARNING

POSSIBLE PROPERTY DAMAGE, PERSONAL INJURY OR DEATH DUE TO FIRE, EXPLOSION, SMOKE, SOOT, CONDENSTAION, ELECTRICAL SHOCK OR CARBON MONOXIDE MAY RESULT FROM IMPROPER INSTALLATION, REPAIR, OPERATION, OR MAINTENANCE OF THIS PRODUCT.

Fig. 8. Safety of setup & use

5 Failure Modes and Effects Analysis

The FMEA is shown in Fig. 8.

Figure 8 Failure modes and effects analysis.

Part name	Function	Failure mode and cause	Failure effect on	Corrective action
Tubular heat exchanger	Contains fluids to heat the furnace	Potential of clogging	Junction box temperature	Should be cleaned during PMs
Pressure switch	Adjusts the pressure	Over time may have faulty wires	Junction box, gas line	Should be checked during PMs
Electrical components	The sensors and electronics that help run the furnace	Furnace may overheat and the components may stop working	Overall furnace	Test sensors and components during PMs
Gas line entrance	Where gas enters the furnace	The pip may get clogged	Overall furnace	Clean every so often for PMs
Gas line valve	Valve to turn off the gas	Potential of degrading over time	Gas line entrance	May be changed every so often
Junction box	The inside area of the furnace	Insulation deterioration	Electrical components/sensors	Replace he insulation when needed

As can be observed from the FMEA, the GMH8 furnace has a number of components which can fail across time, with serious implications for both the system performance as well as the operator's safety. It can also be observed that the implementation of regularly scheduled preventive maintenance directed by the manuals for the furnace can reduce or eliminate the component failures which cause these risks.

6 Conclusions

This safety analysis of the GMH8 furnace shows that by reviewing data for previous accidents as well as by the application of various analysis techniques such preliminary hazard analysis, fault tree analysis, and failure modes and effects analysis, potential hazards associated with the use of the GMH8 furnace can be identified and hazard controls put in place.