TECHNICAL SAFETY BC

Incident Summary #II-968311-2020 (#16370) (FINAL)

SUPPORTING INFORMATION		Incident Date	January 17, 2020
		Location	Surrey
		Regulated industry sector	Gas - Natural gas system
	Impact – Injury	Qty injuries	8
	Impact – Injury	Injury description	Eight people went to hospital with symptoms of carbon monoxide poisoning. One person and an infant were taken by ambulance.
	Impact – Injury	Injury rating	Moderate
	Impact – Damage	Damage description	Furnace heat exchanger failed, producing high levels of carbon monoxide, which entered the home. Redundant safety features (flame rollout switch, air proving switch) failed to control the hazard.
	Impact – Damage	Damage rating	Major
		Incident rating	Major
		Incident overview	A natural gas furnace in a residential home produced elevated levels of carbon monoxide which entered the home and affected eight occupants.
INVESTIGATION CONCLUSIONS		Site, system and components	Residential gas furnaces use the heat produced from the combustion of a gas/air mixture to heat the home. The combustion occurs at the entrance to a heat exchanger. The flue gases produced by combustion pass through the inside passages of the heat exchanger and are carried safely to the outdoors through a venting system connected to the furnace. A blower draws air from inside the home and supplies it into the furnace where it passes around the outside of the heat exchanger. Heat transfers from the heat exchanger to the air which is then distributed thought-out the home through a ducting system, (Diagram 1). High efficiency furnaces incorporate a secondary heat exchanger in addition to the primary heat exchanger. A draft inducer fan first draws the flue gas through the primary heat exchanger then through the secondary one and then outdoors through the venting system. The secondary heat exchanger allows additional heat to transfer to the heating air, reducing the amount of heat lost through the exhaust to the outdoors and increasing the appliances heating efficiency. A by-product of removing more heat from the flue products is the generation of condensation, which accumulates inside the venting system and secondary heat exchanger. High efficiency furnaces are designed to allow the condensate to drain back through the furnace and be piped to a separate drain in the home. The condensate created in a high efficiency furnace is acidic and corrosive to most metals. The venting systems, condensate drains and secondary heat exchangers are required to be made of materials that are not affected by the corrosive properties of the condensate.

	The design of furnace involved in this incident uses carbon steel secondary heat exchanger tubes lined with thermoplastic polypropylene on the inside to protect the steel from the corrosive condensate. Residential gas furnaces incorporate electrical safety circuits designed to shut the furnace off in unsafe conditions. The electrical safety circuits have switches which monitor aspects of the furnaces performance and will interrupt the electrical circuit if any of the monitored values go outside the switches set parameters. When the electrical safety circuit is interrupted the furnace will stop operating. A flame rollout switch is one component of a safety circuit and is installed just upstream of the gas burners. A blockage of the flue passages or venting system can cause the burner flames to roll out the front of the burners. If flames rollout from the burner tubes, the switch will overheat and open the electrical circuit to shut off the furnace. A flame rollout switch must be manually reset if it trips by pressing a button on the outside of the switch. The switches are designed this way because flame rollout is evidence of a serious problem with a furnace or venting system and examination should be done by a qualified individual to identify the issue and not allow the furnace to operate until it is repaired. Natural gas requires a minimum amount of air to burn completely. When the minimum amount of air is not present, the result is incomplete combustion. One of the by-products of incomplete combustion is carbon monoxide (CO). Carbon monoxide is a colourless, odourless, tasteless gas that is toxic to humans and animals (Chart 1). Exposure to carbon monoxide interferes with the body's ability to absorb oxygen, which can result in serious illness or death. (For more information on carbon monoxide check out "CO Safety Tips") Another by-product of incomplete combustion are organic compounds know as aldehydes. While carbon monoxide is odorless, aldehydes have a sharp penetrating odor. The odor of aldehydes differs from odorants added to natural gas for detection. Aldehydes, much like carbon monoxide, are toxic to humans and animals.
Failure scenario(s)	A natural gas furnace was operating in a residential home with eight occupants. The furnaces secondary heat exchanger had corroded. The corrosion created holes in the heat exchanger and restricted the airflow of the combustion products through it. The restricted airflow led to incomplete combustion and the production high levels of carbon monoxide and aldehydes. The carbon monoxide and aldehydes then entered the home creating a hazardous atmosphere inside..
Facts and evidence	A Carrier model 58MCB080 (Image 2) high efficiency natural gas furnace had been installed in a residential home. The original gas installation permit indicates the furnace was installed in the home in March 2007. The furnace had been operating in the home for just under 13 years prior to the incident. At the time of the incident the owner stated that they had purchased the home approximately 5 years prior. They said that they had not had any issues with the operation of the furnace from the time they moved in until the beginning of the 2019 Winter season. When they first started the furnace for that season they heard a loud noise that they described as a rattle that sounded like "the starting of a tractor". They said the noise soon stopped and the furnace appeared to be operating normally and that the noise could not be replicated on future furnace start-ups. The rattling noise prompted the owner to replace the furnace air filter. They began to notice a faint

smell that they believed to be gas near the furnace when it was operating. The smell worsened over time and was more noticeable in the basement where the furnace was located. Just before the incident a neighbor alerted them of a very strong odour at the exterior of the house where the furnace vent termination was located. The odour was believed to be natural gas so they notified the natural gas utility company.

The natural gas utility company dispatched a technician to investigate. The technician's notes indicate that after entering the home, 176 parts per million (ppm) of carbon monoxide was measured in the ambient air in the basement (Chart 1). The technician found the furnace was producing high levels of carbon monoxide and no other sources could be identified. The technician shut off the furnace and requested an ambulance attend the scene due to the symptoms some of the occupants were experiencing. The furnace was shut off and a red tag was affixed by the technician identifying it as unsafe to operate and the occupants were informed it was unsafe to use until it could be repaired or replaced.

The owner stated that the occupant who was taken to hospital by ambulance with their infant was experiencing dizziness and shortness of breath. They were treated with oxygen at the hospital and released later that evening. The rest of the occupants of the home went to hospital for testing.

A contractor was hired to replace the furnace. The contractor stated that when he replaced the furnace no corrosion could be seen on the secondary heat exchanger while the furnace was still installed. He noticed that the vent for the furnace terminated horizontally out the side of the house and it had a 90 degree elbow on it pointing straight down into a window well for the basement that had an opening window. The contractor inspected the rest of the existing furnace venting system and did not find any evidence of separations, cracks, signs of leakage or overheating. When he installed the new furnace he relocated the furnace vent termination so it was farther away from the basement window. The owner stated that when the incident occurred it was cold outside and the basement window by the furnace termination was closed.

The furnace was disassembled for closer examination after it was removed from the home. Photographs show the primary heat exchanger did not have any holes, cracks or signs of corrosion. While removing the secondary heat exchanger, corrosion and holes were observed on the inlet side to the heat exchanger tubes. When the secondary heat exchanger assembly was being disassembled, all of the tubes broke away from their connection points at the tubes inlets without a deliberate attempt to do so. This was due to excessive corrosion. Photographs show the separation of the tubes and the holes from corrosion (Image 3-4-5) and also the blocked internal passages from the corrosion and delaminated polypropylene liner (Image 6).

Evidence Examination

The inlets to the furnace's secondary heat exchanger tubes had corroded and the interior polypropylene lining had delaminated which restricted the airflow through them. The restricted airflow reduced the amount of air at the point of combustion in the burner box. The unbalanced air/fuel ratio produced elevated levels of carbon monoxide in the flue products.

During operation of the furnace, the restricted flue passages caused the flames to roll out of the burner tubes inside of the burner box. Flame rollout did not cause the safety switch to overheat and allowed the furnace to continue to operate in an unsafe

		condition. The switch may not have activated because the flame rollout was mainly occurring on the opposite side of the burner box from the switch location. Failure analysis of the heat exchanger was conducted by an independent laboratory which provided an expert report detailing the failure mechanism and cause of the failure. The expert report concluded that the secondary heat exchanger failed due to corrosion caused by rapid degradation of the polypropylene lining. The rate of corrosion is related to time in service. The laboratory report states that it is expected that all furnaces of this type would be damaged from similar corrosion. This corrosion was observed to have plugged some tubes which could result in a positive pressure upstream of the tubes, at the location of the corrosion holes. This positive pressure would then allow hazardous flue gases to contaminate the air inside the home. The polypropylene liner inside the tubes is intended to protect the steel tubes from corrosive gases and condensate inside the tubes. The laboratory report stated that the polypropylene material was broke down due to the sulphuric acid present in flue gas condensate. Carrier states that the life expectancy of their gas furnaces is 20 to 25 years. This furnace failed within 13 years of use.
	Causes and contributing factors	The cause of the incident was the furnace secondary heat exchanger design which used polypropylene laminated steel materials. Rapid and excessive corrosion of these materials restricted airflow through the furnace resulting in production of carbon monoxide due to incomplete combustion, which then entered the home. A contributing factor was the failure of the flame rollout switch to stop the operation of the furnace.

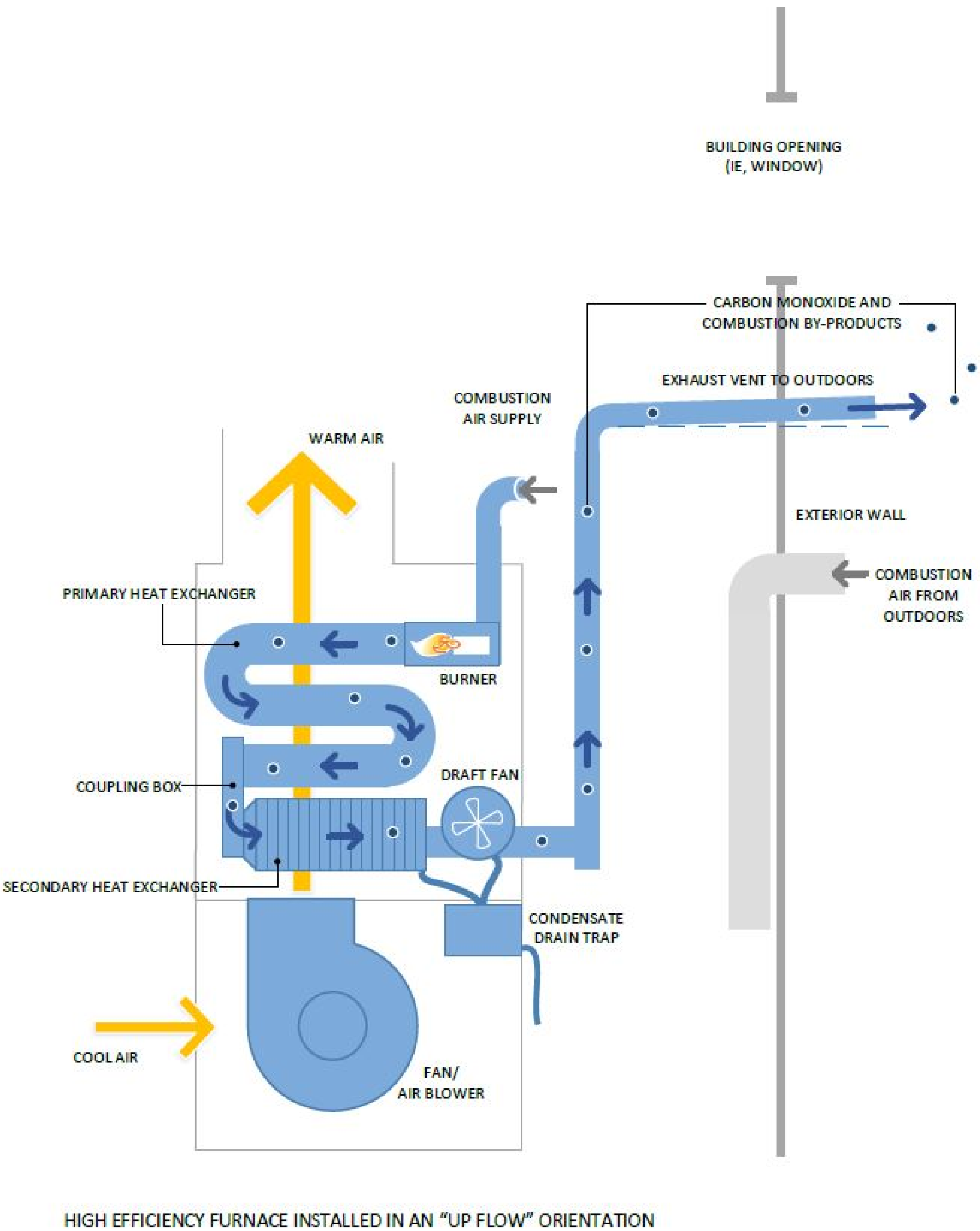

Diagram 1 – Showing typical furnace operation. Arrows show direction of flue gas flow and dark coloured dots represent carbon monoxide.

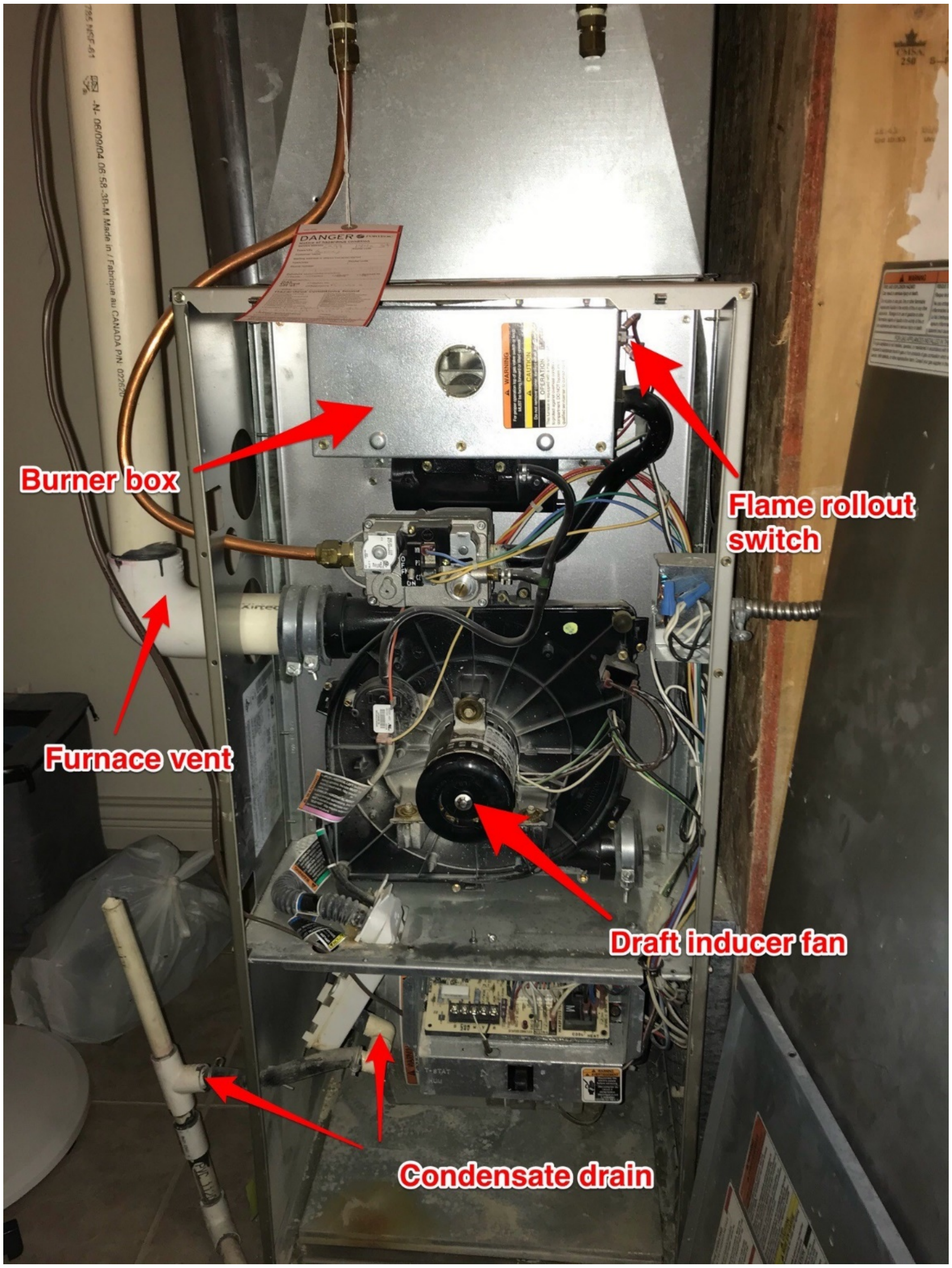

Image 1 – Furnace with cover panels removed, prior to the furnace being removed from the house for testing.

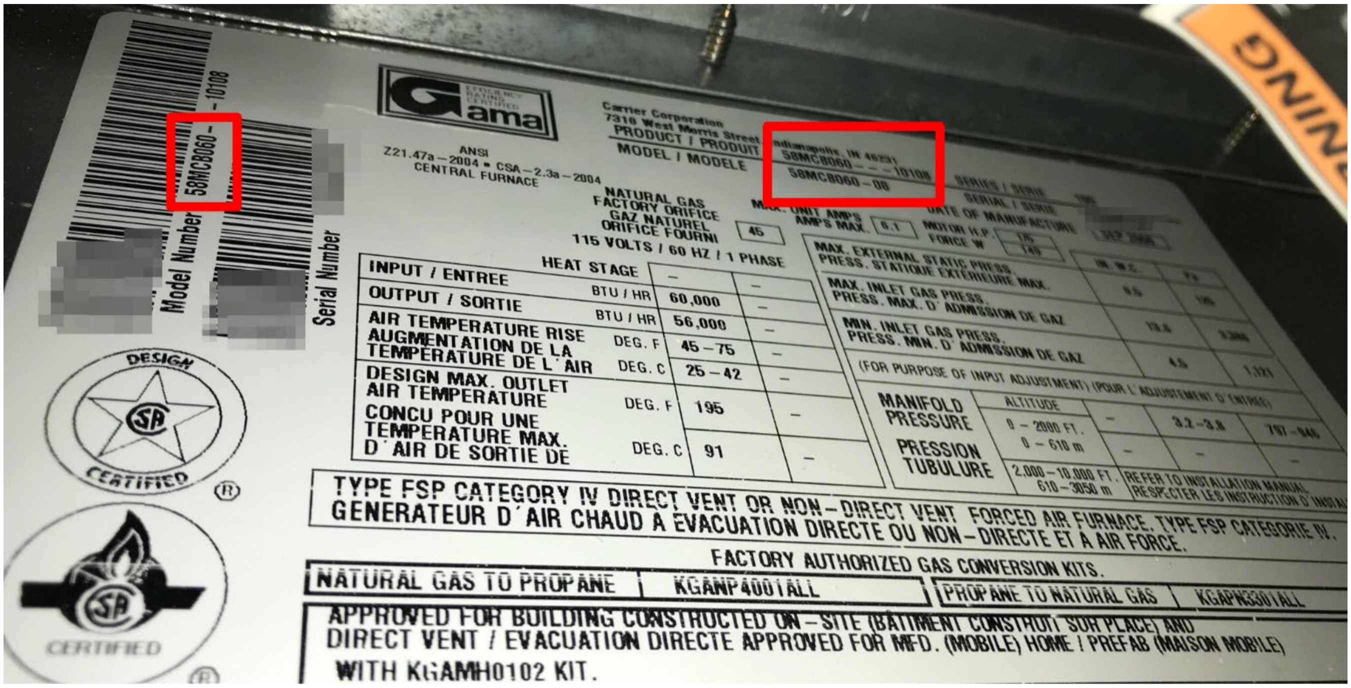

Image 2 – Furnace data tag identifying it as a Carrier model # 58MCB060

Image 3 – Heat exchanger removed from furnace and dismantled. End screws on the heat exchanger cabinet and secondary heat exchanger tubes had completely separated from the coupling box

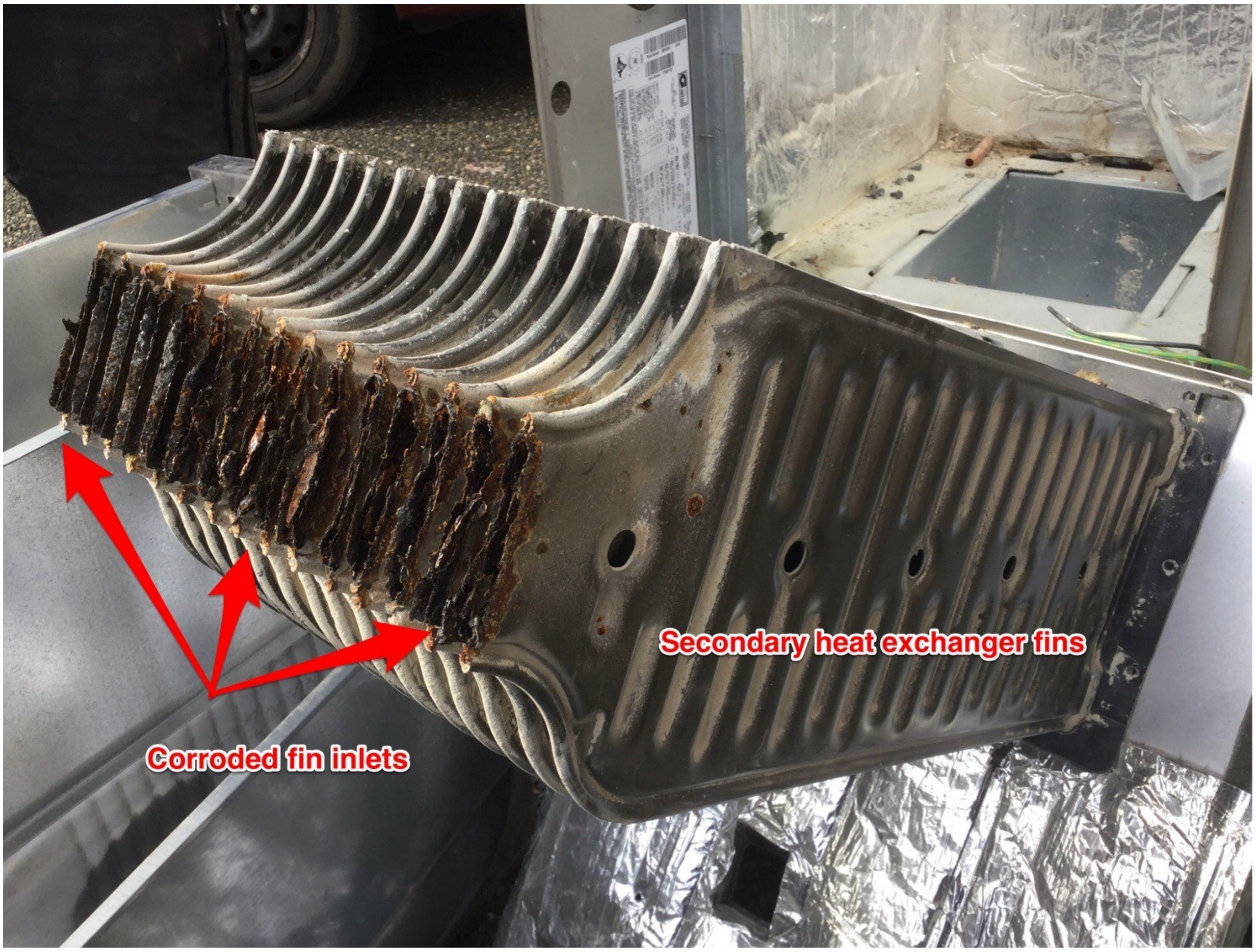

Image 4 – Secondary heat exchanger tube inlets

Image 5 - Secondary heat exchanger tube inlet

Image 6 - Secondary heat exchanger tube inlets

Image 7 - Secondary heat exchanger tube inlet connection points to the coupling box

Image 8 - Secondary heat exchanger tube split apart for examination

Properties of Carbon Monoxide

Colourless	Cannot be seen.
Tasteless	Cannot be detected through the sense of taste.
Odourless	Cannot be detected by sense of smell, However, CO can also be accompanied by aldehydes. Aldehydes' odour can somewhat resemble vinegar, which can be detected by the sense of smell, and may also result in a metallic taste in the mouth.
Non-irritating	Carbon Monoxide will not cause irritation. However, aldehydes usually present with higher levels of CO will irritate the eyes, nose, and mucous membranes.
Specific gravity	Slightly lighter than air (Sg 0.975). It may, but not always collect near the ceiling, and mixes freely with air.
Flammable (explosive) limits	CO is flammable between concentrations of 12.5% to 74% when mixed with air. Its ignition temperature is 609ºC (1128ºF).
Toxic	Can cause death if enough is absorbed into the bloodstream.

Chart 1 Properties of Carbon Monoxide – From Technical Safety BC's "Carbon Monoxide Handbook"