HIGH-PRESSURE GAS COOLING: THE CASE FOR HYDROGEN

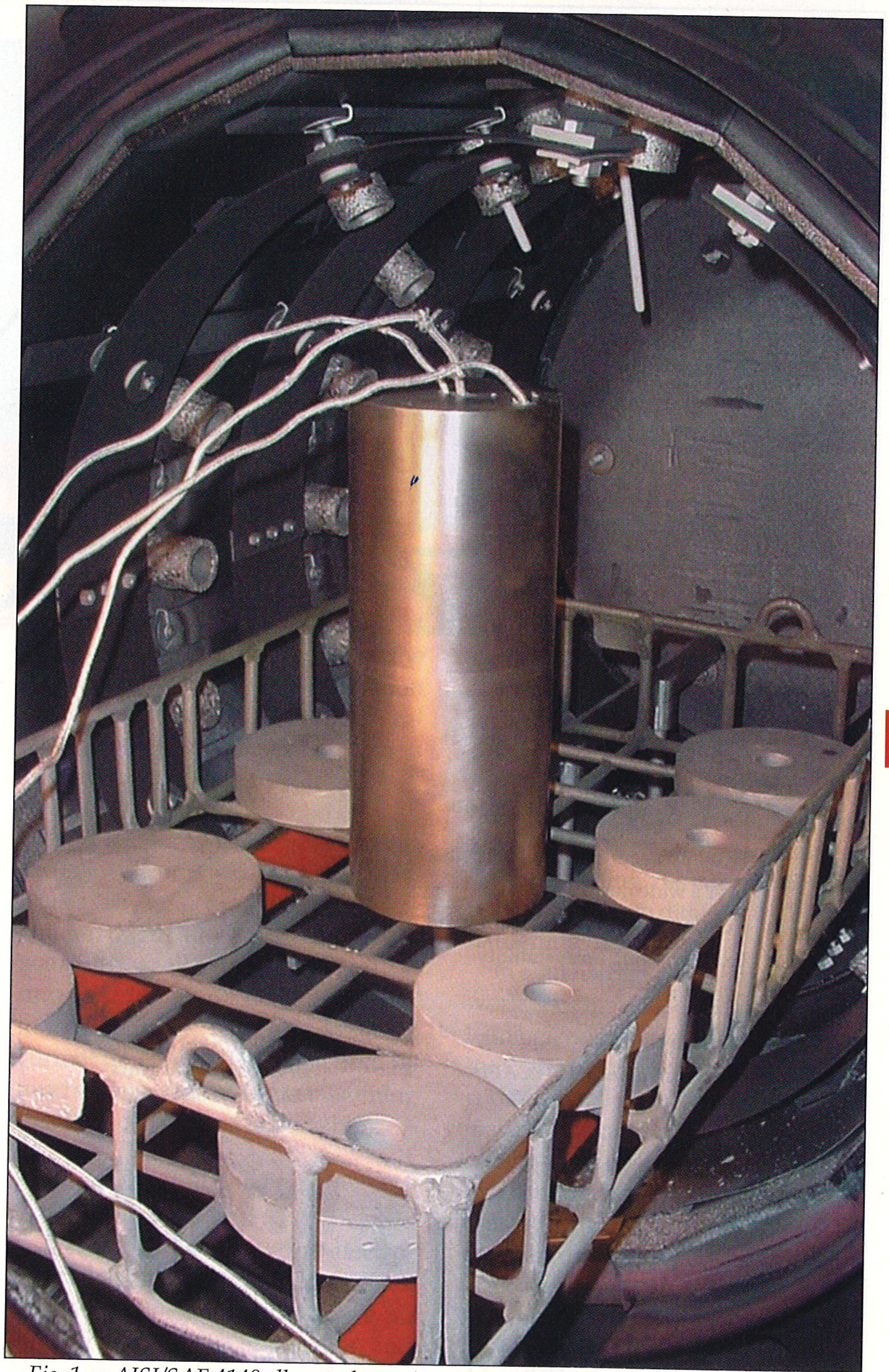

Fig. 1 — AISI/SAE 4140 alloy steel test piece with surface core and radius core thermocouples attached. The bar is 12 in. (305 mm) long and 5 in. (125 mm) in diameter. Note the ballast used to bring the vacuum furnace load up to a constant 200 lb (90 kg).

Hydrogen's cooling power makes it an attractive higher performance alternative to nitrogen as a quenching gas, particularly in light of the escalating price of helium. However, safety issues must be resolved before heat treaters will adopt it.

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The indisputable and increasing need for heat treaters to save energy, boost productivity, minimize distortion, and improve metallurgical properties while reducing environmental impacts should encourage vacuum furnace manufacturers to place greater emphasis on enhancing gas quenching performance. The purpose of the study summarized in this article was to analyze the cooling performance of the various quench gases that are available to vacuum heat treaters.

The benchmark gas for quenching, and the industry standard for many years, has been nitrogen. Alternatives for faster cooling include hydrogen and helium. Theoretically, hydrogen should cool 50% faster than nitrogen and helium should cool 33% faster

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than nitrogen, while hydrogen's speed edge over helium is predicted to be 17%.[1]

However, helium's cost is skyrocketing and world reserves of the gas are finite. This is why engineers at Solar Atmospheres are focusing on understanding the high-pressure cooling properties of hydrogen. Safety issues, of course, must be resolved, so they also are working on this aspect of hydrogen gas quenching, and are being guided by the National Fire Protection Assn.'s NFPA 86: Standard for Ovens and Furnaces.

Study of Quenching Gases

The heat transfer rate of a gas is affected by changes in gas pressure, velocity, temperature, and composition, and by the geometry of the part being cooled. The Solar Atmospheres study focused on gas composition. All other conditions were held constant.

Procedure: The alloy used was AISI/SAE 4140, an aircraft quality Cr-Mo steel (UNS G41400). To investigate the cooling effects of the gases nitrogen, helium, and hydrogen on different cross sections, three sizes of 12 in. (305 mm) long round bar were chosen: 1, 5, and 8 in. (25, 125, and 205 mm) in diameter. Ballast weights were used to ensure constant loads of 200 lb (90 kg) for each run.

Work thermocouples were inserted into 0.25 in. (6 mm) in diameter holes drilled parallel to the bars and 6 in. (150 mm) deep, at both the center (radius core) and 0.25 in. (6 mm) from the outside diameter (surface core). A 5 in. (125 mm) in diameter bar with thermocouples inserted is shown in Fig. 1.

Loads were austenitized in a vacuum furnace at 1700°F ± 15°F (925°C ± 8°C) and held for 45 minutes on the radius core work thermocouple. Gas quenching was at 10 bar for the three media: nitrogen, helium, and hydrogen. All test pieces were then vacuum tempered at 325°F ± 25°F (165°C ± 14°C) for 1 hour. All variable speed drives for the 100 hp (75 kW) blower motor were set at 5000 rpm.

Temperatures were logged once a second during cooling using a high-speed digital recorder. Temperatures indicated by furnace (control) thermocouples also were recorded.

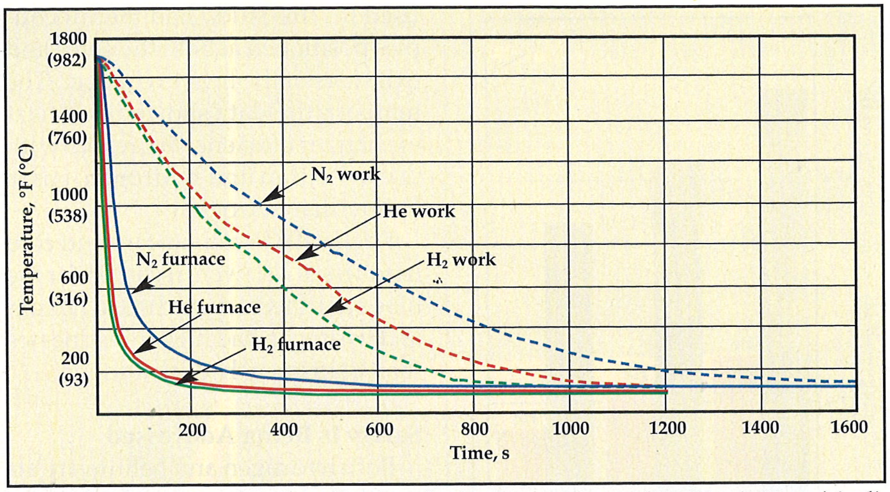

Fig. 2 — Furnace and work cooling data for the three test runs of the 5 in. (125 mm) in diameter, 12 in. (305 mm) long AISI/SAE 4140 alloy steel bar.

Table 1 — Cooling rate improvement over nitrogen

Test bar diameter, in. (mm)	Quench gas (all at 10 bar pressure)	Improvement, %			
		Cooling rate to 1200°F (650°C)	Cooling rate to 700°F (370°C)	Cooling rate to 300°F (150°C)	Average
1 (25)	He	44	50	53	49
	H_2	74	71	57	67
5 (125)	He	45	27	29	34
	H_2	51	41	43	45
8 (205)	He	33	27	25	28
	H_2	34	30	28	31

Results Confirm Theory

Furnace and work cooling data for the three test runs of the 5 in. (125 mm) in diameter steel bar are plotted in Fig. 2. Temperature data points for the test pieces were averages of the values recorded by the "surface core" and "radius core" thermocouples. Graphs also were constructed for the runs of the 1 and 8 in. (25 and 205 mm) in diameter steel test pieces.

Three temperatures were chosen as critical temperatures to analyze: 1200, 700, and 300°F (650, 370, and 150°C). Cooling improvements for helium and hydrogen versus nitrogen were then calculated for the three different test pieces (Table 1).

Test data confirm that actual cooling rates closely track those derived from theory. Cooling data for 1 and 5 in. (25 and 125 mm) in diameter bars exceed predictions, while data for 8 in. (205 mm) bars are slightly less than predicted (Fig. 3).

Also noted: The vacuum furnace

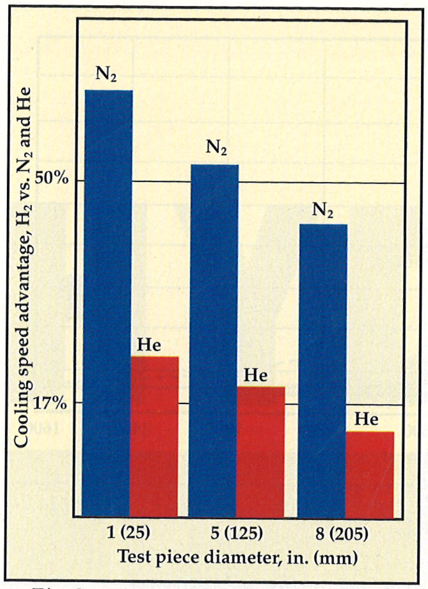

Fig. 3 — Summary of Solar Atmospheres' quenching gas tests. According to theory, hydrogen should cool 50% faster than nitrogen and 17% faster than helium. Cooling data for 1 and 5 in. (25 and 125 mm) in diameter bars exceed predictions, while data for 8 in. (205 mm) in diameter bars are slightly less than the prediction. Note that part geometry is a critical factor.

used for this study had thermocouples positioned at both the entry and exit sides of the heat exchanger. The temperature data showed that heat exchanger efficiency increases with use of helium and hydrogen, gases lighter than nitrogen.

Rockwell C-scale surface and core hardnesses also were recorded for the nine bars. Pieces quenched in helium and hydrogen had higher hardnesses than bars quenched in nitrogen.

Safety Is Being Addressed

Both hydrogen and helium are attractive alternatives to the benchmark nitrogen — cooling rates are improved, heat exchangers are more efficient, and surface and core hardnesses are increased.

The major drawbacks to use of helium are its high price and diminishing supply, neither of which is likely to improve.

The properties of hydrogen, however, have proven to be superior to helium at one-fifth the cost. But use of hydrogen as a quench gas has traditionally been taboo for safety reasons — it can become very unstable should air enter the furnace. If vacuum heat treaters are to make use of hydrogen quenching, new and more stringent safety precautions must be developed and implemented. To this end, Solar engineers and others in the industry are diligently exploring ways to safely quench with hydrogen.

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Reference

1. Theoretical cooling rate data courtesy Air Products & Chemicals Inc., Allentown, Pa. (www.airproducts.com). Data are for cooling from 2000°F (1095°C) to 300°F (150°C). Note: Argon cools about 25% slower than nitrogen.