US007674320B2

(12) **United States Patent**
**Vadivelu**

(10) **Patent No.: US 7,674,320 B2**
(45) **Date of Patent: Mar. 9, 2010**

(54) **PREPARING HYDROGEN FOR CRYO-ADSORBER STORAGE**

(75) Inventor: **Senthil Kumar Vadivelu**, Bangalore (IN)

(73) Assignee: **GM Global Technology Operations, Inc.**, Detroit, MI (US)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 138 days.

(21) Appl. No.: **11/877,729**

(22) Filed: **Oct. 24, 2007**

(65) **Prior Publication Data**

US 2009/0107155 A1 Apr. 30, 2009

(51) **Int. Cl.**
***B01D 53/02*** (2006.01)

(52) **U.S. Cl.** ..... **95/115**; 95/90; 95/94; 95/116; 95/141; 96/108; 96/126; 96/135; 420/900; 423/644; 423/648.1; 423/658.2

(58) **Field of Classification Search** ..... 95/90, 95/94, 115, 116, 141; 96/108, 126, 135; 420/900; 423/644, 648.1, 658.2
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

| | | | | |
|---|---|---|---|---|
| 4,154,364 | A * | 5/1979 | Hagiwara et al. | 220/560.12 |
| 4,783,329 | A * | 11/1988 | Maeland et al. | 423/644 |
| RE35,725 | E * | 2/1998 | Briesacher et al. | 95/115 |
| 6,383,259 | B1 * | 5/2002 | Lim et al. | 95/90 |
| 6,503,298 | B1 * | 1/2003 | Monzyk et al. | 95/96 |
| 6,733,563 | B2 * | 5/2004 | Fujita et al. | 75/352 |
| 7,166,150 | B2 * | 1/2007 | Torgersen et al. | 96/108 |
| 7,378,188 | B2 * | 5/2008 | Struthers et al. | 429/218.2 |
| 2001/0027724 | A1 * | 10/2001 | Oshima et al. | 96/135 |
| 2003/0209296 | A1 * | 11/2003 | Aono et al. | 148/421 |
| 2005/0061685 | A1 * | 3/2005 | Struthers et al. | 206/0.7 |
| 2006/0101943 | A1 * | 5/2006 | Snow et al. | 75/252 |

FOREIGN PATENT DOCUMENTS

| | | |
|---|---|---|
| JP | 6068433 | 8/1994 |
| JP | 2003065497 | 3/2003 |
| JP | 2007046655 | 2/2007 |
| JP | 2007046656 | 2/2007 |

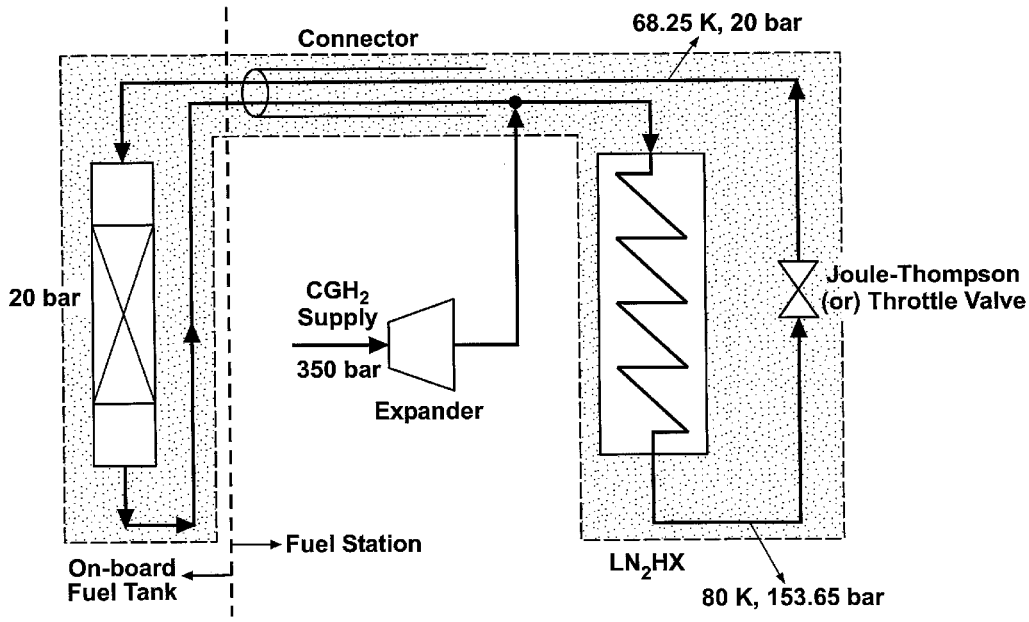
OTHER PUBLICATIONS

Written Opinion of the International Searching Authority for PCT/US2008/076935 dated Mar. 27, 2009.
International Search Report for PCT/US2008/076935 dated Mar. 27, 2009.

* cited by examiner

*Primary Examiner*—Robert J Hill, Jr.
*Assistant Examiner*—Christopher P Jones
(74) *Attorney, Agent, or Firm*—Reising Ethington P.C.

(57) **ABSTRACT**

Hydrogen gas at a hydrogen refueling site is cooled below liquid nitrogen temperature (e.g., about 80K) for more efficient adsorption of hydrogen on hydrogen adsorbent particles in the fuel storage of a hydrogen powered vehicle. When compressed hydrogen gas is available it may be cooled with liquid nitrogen and then sub-cooled below about 70K by a Joule-Thompson expansion. When liquid hydrogen provides hydrogen gas it may be cooled below liquid nitrogen temperatures by mixing with liquid hydrogen or by heat exchange with liquid hydrogen.

**12 Claims, 3 Drawing Sheets**