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Design of High Pressurized Hydrogen Gas Cylinder

Abstract:

The main objective of this paper is to propose the possible dimensions of cylinder which is used to store the hydrogen gas. Furthermore, according to given dimensions, design hydrogen gas cylinder based on the material properties (which is required for fabrication). The materials for manufacturing of Hydrogen gas cylinder (HGC) can be steel. But the steel is heavier and has got safety problem. So there arises a need to rectify these problems using some other alternatives. In this journal different alternatives are examined and an appropriate material is selected. This project is to develop theoretical calculation of dimensions for high pressure vessel. Results were generated according to ASME VIII-1 design code and Hoop's stress theory.

Keywords: Hydrogen gas cylinder, Dimensions, High pressure vessel, ASME (American Society of Mechanical Engineers) Code VIII, Division -1, Hoop's Stress.

Introduction:

Hydrogen is a colorless, odorless, tasteless, highly flammable gas. It is also the lightest-weight gas. Since hydrogen is noncorrosive, special materials of construction are not normally required. Vessels and piping must be selected and designed to withstand the pressure and temperatures involved and comply with applicable codes and regulations.

Hydrogen Gas cylinder is leak proof container used to store hydrogen gas at a pressure different from the ambient pressure. Hydrogen cylinder is a kind of pressure vessel that requires high tensile and compressive strength to store pressurized hydrogen gas. The material of pressure vessel may be brittle such as cast iron, or ductile such as mild steel. According's to the dimensions, the pressure vessels can be classified as thick shell or thin shell. If the wall thickness of the pressure vessel is less than $1/10^{th}$ of the diameter of the shell, then it is called thin shell pressure vessel and if the wall thickness of the shell is greater than $1/10^{th}$ of the diameter of the shell, then it is called as thick shell pressure vessel. This paper basically deals with design of thin hydrogen gas cylinder under given internal pressure at a room temperature. Two types of tensile stresses occur in this cylinder. One is circumferential or hoop stress and the other one is longitudinal stress. Longitudinal stress is half of the circumferential or hoop stress. Therefore, the design of this pressure vessel must be based on the circumferential or hoop stress. Various formulas, theories and methods are being developed to find out the exact dimension. In this project manual theoretical calculation is done to find out the dimensions. So, the results were generated according to ASME VIII-1 design code and Hoop's stress theory.

Problem Statement:

Design the hydrogen cylinder manually is all about approximating the dimension of the hydrogen gas cylinder. The most challenging part of this project is to proposed the possible dimensions for design of highly pressurized hydrogen tank and selection of the appropriate materials for its fabrication. based on possible dimension.

Properties of Gaseous Hydrogen:

Table 1: Gaseous Hydrogen Physical and Chemical Properties (Retrieved from Safetygram 4 @ Air Product)

Chemical Formula	H_2
Molecular Weight	2.016
BOILING POINT AT 1 ATM	(–252.9°C
FREEZING POINT AT 1 ATM	(–259.2°C
CRITICAL TEMPERATURE	–240°C
CRITICAL PRESSURE	12.8 bar
DENSITY, GAS AT 70°F (21°C), 1 ATM	0.1 g/l
SPECIFIC GRAVITY, GAS (AIR=1) AT 68°F (20°C), 1 ATM	0.07
SPECIFIC VOLUME AT 70°F (21°C), 1 ATM	11.99 m^3/kg
LATENT HEAT OF VAPORIZATION	446 kJ/kg
FLAMMABLE LIMITS AT 1 ATM IN AIR	4%–75% (by volume)
AUTOIGNITION TEMPERATURE AT 1 ATM	(560°C)

1. Generating Volume of gaseous hydrogen and Volume of cylinder:

Assumption:

Mass of hydrogen gas (m)= 6 kg at room temperature (21 ^{0}C) and 1 atm Pressure.

Let,

Volume of gaseous hydrogen (21 ^{0}C), V1 = 35.959 m^3

Pressure of hydrogen gas, P1 = 1 atm = 1.01325 bar

Inside pressure of cylinder, P2 = ?,

Volume of cylinder = $V2 = \pi r^2 l$

By applying Gas Law,

P1V1 = P2V2

Table 2: Volume of 6 kg hydrogen gas.

Retrieved from http://www.airproducts.com/Products/Gases/gas-facts/conversion-formulas/weight-and-volume-equivalents/hydrogen.aspx

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Hydrogen - Weight and Volume Equivalents

Weight of Liquid or Gas		Volume of Liquid at Normal Boiling Point		Volume of Gas at 70°F (21°C) and 1 atm	
lb	kg	L	gal	cf	m^3
1.000	0.454	6.409	1.693	192.00	5.437
2.205	1.000	14.132	3.733	423.360	11.988
0.156	0.071	1.000	0.264	29.952	0.848
0.591	0.268	3.788	1.000	113.472	3.213
5.208	2.362	33.381	8.818	1000.00	28.317
0.184	0.083	1.179	0.312	35.328	1.000

Enter numbers in boxes below for conversion values.

6.614	3	42.390	11.198	1269.888	35.959

Table 3: Internal Pressure Based on Dimension of Cylinder.

Mass	Diameter (in m)	Length (in m)	Volume of cylinder at 21 ^{0}C	Internal Pressure (bar)
3 kg	0.4	**4**	**0.50265**	**72.5**
		3	0.3770	97
		2	0.2513	145

Mass	Diameter (in m)	Length (in m)	Volume of cylinder at 21 ^{0}C	Internal Pressure (bar)
3 kg	0.3	4	0.2827	128.86
		3	0.2120	171.8
		2	0.1413	258

2. Design calculation and Analysis:

An equation applying Hoop stress concept is derived to establish minimum shell thickness in a thin cylinder, given by:

1. According to ASME Code VIII-1,

$$\mathbf{t} = \frac{PR}{SE-0.6P} \quad \text{(For cylindrical Portion)}$$

$$t = \frac{PR}{2SE - 0.2\,P} \quad \text{(For hemispherical end dome)}$$

2. According to Hoop's Stress theory:

$$t = \frac{PR}{\sigma t} \quad \text{(For cylindrical Portion)}$$

$$t = \frac{PR}{2\sigma t} \quad \text{(For hemispherical end dome)}$$

where,
t = minimum shell thickness
P = internal pressure
S = allowable stress
E = joint efficiency = 1 (assume)
R = inside radius
σt – Yield strength of materials

Note: The difference is the additional term of 0.6*P* in the denominator. This term was added by the ASME to take into consideration of the nonlinearity in stress that develops in thick cylinder.

2.1 Thickness established on the basis of material properties:

2.1.1 Carbon Composite fiber std cf fabric:

Yield strength of materials (σt) = 600MPa
Density = 1.60 g/cc

Table 1: Table for thickness and mass of cylinder for Carbon Composite.

Diameter (in m)	Length (in m)	Thickness (in mm)				Internal Pressure (bar)
		Based on ACME CodeVIII-1		Based on Hoop's stress Theory		
		shell	End cap	shell	End cap	
0.4	**4**	**2.45**	**1.20**	**2.42**	**1.21**	**72.5**
	3	3.265	1.62	3.23	1.62	97
	2	4.90	2.42	4.83	2.41	145

Diameter (in m)	Length (in m)	Thickness (in mm)				Internal Pressure (bar)
		Based on ACME CodeVIII-1		Based on Hoop's stress Theory		
		shell	End cap	shell	End cap	
0.30	4	3.24	1.60	3.2	1.6	128.6
	3	4.53	2.23	4.45	2.225	178.1
	2	6.62	3.23	6.45	3.225	258

Determination of Total Volume and Weight of Cylinder:

Dimensions: **For Shell**

Outer radius (R_2) = 200+2.45= 202.45 mm = **0.20245 m**,

Inner radius (R_1) = 200 mm = **0.2 m**,

Length (l) = **4 m**

Volume of Shell (V_1) = $\pi*((R_2)^2 - (R_1)^2) * l$ = **0.012390 m^3**

For End Cap:

Outer radius (R_2) = 200+1.20 = 201.2 mm = **0.2012 m**

Inner radius (R_1) = 200mm = **0.2 m**

Volume of end cap (V_2) = $\frac{4\pi}{3}\{(R_2)^3 - (R_1)^3\}$ = **0.0006068 m^3**

Total Volume (V) = $V_1 + V_2$ = 0.012390 m^3 + 0.0006068 m^3 = **0.0129968 m^3**

Weight of cylinder without hydrogen gas (m) = density * total volume

= 1600 * 0.0129968 = **21 kg**

Note: For this Composite fiber material density = **1600 kg/m^3**

Weight of cylinder with hydrogen gas = 21 +3 = **24 kg**.

Final Result:

Mass of Hydrogen gas (kg)	Internal pressure (bar)	Length (m)	Diameter (m)	Thickness (mm)	Yield Strength of material (Mpa)	Density of material	Weight of Cylinder (without gas)	Weight of Cylinder (with gas)
3 kg	72.5	4	0.4	2.45	600 Mpa	1600 kg/m^3	21 kg	24 kg

As per requirement of storing 3kg of hydrogen gas, it is found that the length, diameter and thickness of the tank should be 4m, 0.4m and 2.45mm respectively. Moreover, the selected material is carbon composites having yield strength and density of 600Mpa and 1600 kg/m^3. Similarly, the weight of cylinder (without hydrogen gas) is found to 21 kg.

Conclusion:

This paper focused on the design of safe and reliable Hydrogen Tank which can store Hydrogen gas as reliable Fuel for Hydrogen Powered Train. During the span of this project, the major challenges were to reduce the weight of the Tank, Optimized Dimensions, Optimized the Cost and should be more reliable. Different possible dimensions for different types of materials are proposed and selection of best material which ensures the tackling constraint of size/weight/shape/cost of tank.

Future Work:

Once the dimension (length and diameter) gets fixed then the researchers may design and simulate the different parameters like efficiency, weight and so on, of hydrogen tank using the software like CATIA, SolidWorks and ANSYS for the better and durable product.

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