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Mixture of Alloys Used for Building a Regenerator to Bring Down the Temperature of Liquid Hydrogen (Lh_2) Below 20k

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Abstract

This paper deals with cryocoolers which is usually a standalone cooler and it is used to cool some particular application to cryogenic temperatures. Here we are going to see how we can improve the performance of coolers for the Zero Boil Off (ZBO) storage of Liquid Hydrogen (LH_2) and also we are going to deal with how we can bring down the temperature of Liquid Hydrogen (LH_2) lesser than 20K by using high heat capacity rare earth alloys. This is because no long lived 30K or colder closed cycle coolers have flown in space. Current commercial, non-flight pulse tube cryocoolers are available for temperatures down to 3K , however these machines are not space qualified and are inefficient. The main aim of Liquid Hydrogen (LH_2) coolers is to achieve high efficiency and reliability at lower operating temperatures. My idea is to build a regenerator with a combination of alloys which can achieve high efficiency at very high temperatures and provide maximum power levels to reach our target. The materials discussed here mainly will be to resist the very high temperatures produced and reducing the temperature of Liquid Hydrogen (LH_2) maximum below 20K.

1. Introduction

The cryocoolers are the components used in vehicles for space travels and for very long space probes. They consists some important components like the regenerators and the ideal heat exchangers. A regenerator is an important component of cryocoolers consists of a matrix of a solid porous material, such as granular particles or metal sieves, through which gas flows back and forth. Periodically heat is stored and released by the material. The heat contact with the gas must be good and the flow resistance of the matrix must be low. These are conflicting requirements. The thermodynamics and hydrodynamic properties of regenerators are very complicated, so one usually makes simplifying models.

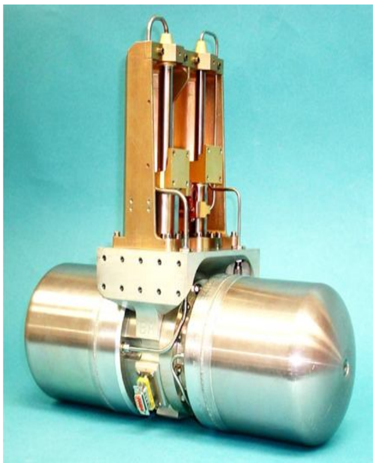

Fig. 1: Above shown is a picture of a cryocooler.

Fig. 2: Above shown is a picture of regenerator

Fig. 3: Shown above is a Radial flow heat exchanger.

Heat exchangers are important components of all cryocoolers. Ideal heat exchangers have no flow resistance and the exit gas temperature is the same as the body temperature T_X of the heat exchanger. Note that even a perfect heat exchanger will not affect the entrance temperature T_i of the gas. This leads to losses. Now let us see what are the combination of alloys materials can be used to build a regenerator to achieve high efficiency at very high temperatures and provide maximum power levels.

List of Alloys for Regenerator at Cryogenic and Elevated Temperatures:-

Table 1: Alloys for regenerator at cryogenic and elevated temperatures.

Sl. No	Alloys
1	Al-Zn-Mg-Cu
2	2014
3	2024
4	Al-Cu-Mg alloy with silver additions
5	5083
6	5456
7	5083-O
8	6061-T651
9	2219-T87
10	2124-T851
11	2024-T851

12	2214
13	2419
14	7050
15	7475

2. Properties of Al-Zn-Mg-Cu

These alloys develop the highest room-temperature tensile properties of any aluminum alloys produced from conventionally cast ingots. However, the strength of these alloys declines rapidly if they are exposed to elevated temperatures due mainly to coarsening of the fine precipitates on which the alloys depend for their strength.

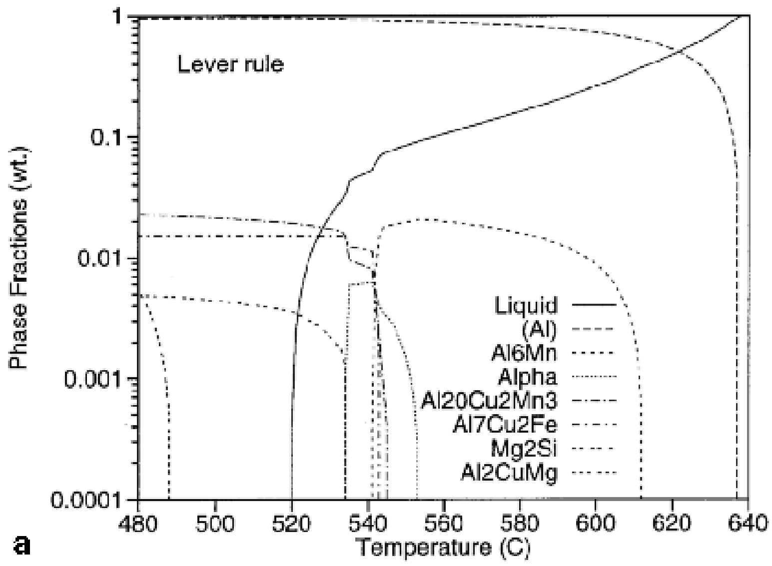

Fig. 4: The above graph shows the variation of Al-Zn-Mg-Cu with temperature.

3. Properties of 2014 and 2024

The 2014 and 2024 alloys perform better above these temperatures but are not normally used for elevated-temperature applications. Strength at temperatures above about 100 to 200°C is improved mainly by solid-solution strengthening or second phase hardening.

4. Properties of Al-Mg-Cu Alloy with Silver Addition

The Al-Mg-Cu alloy with silver added to it improves its creep properties. Iron is also being used to improve creep properties. They posses very high strengths due to the presence of silver.

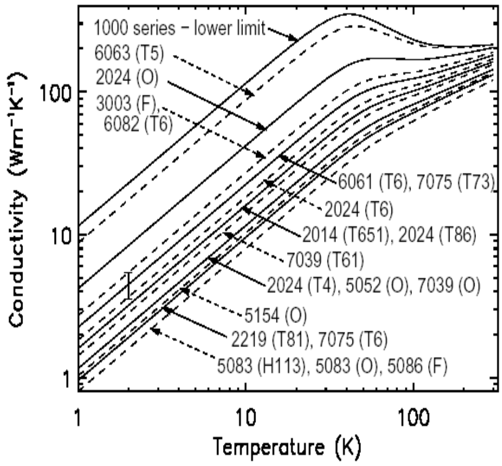

Fig. 5: The above graph shows the variation of conductivity of various alloys with respect to temperature.

The graph above gives us the idea of selecting the alloy having the highest conductivity at increasing temperatures.

Table 2: Above given is a table with the conductivity of different Si-Fe-Mn-Zn material.

Si	Fe	Mn	Zn	Conductivity (%IACS)
0.97	1.45	0.31	0.51	50.3
0.96	1.53	0.42	0.46	49.8
0.86	1.54	0.41	0.46	50.7
0.84	1.85	0.42	0.47	51.4
0.75	1.49	0.41	0.47	50.5
0.80	1.51	0.52	0.46	49.7
1.02	1.50	0.32	0.45	50.2
0.85	1.44	0.39	0.54	51.1
0.83	1.47	0.38	0.92	50.3
0.89	1.52	0.38	1.43	49.6
0.83	0.93	0.37	0.93	49.5
0.86	0.29	0.41	0.88	48.3
0.87	1.41	0.41	0.95	49.4
0.86	1.68	0.41	0.95	50.1
0.90	1.40	0.29	1.08	49.9
0.98	1.73	0.34	1.15	49.6
1.04	1.90	0.45	1.09	49.3
1.02	2.22	0.55	0.98	49.4

From the list of materials given above we can see that a combination having 51.4% of conductivity. This combination can also provide a good efficiency to the regenerators at very high temperatures. They also provide good power levels to achieve the desired target so that the Zero Boil Off (ZBO) point can be bought below 30K for Liquid Hydrogen (LH_2). The conductivity of this combination also shows us that the heat capacity is very high and can be used at cryogenic temperatures.

Some List of Aluminium Alloys of the 1000 Series

Table3: shows the 1000 series of Aluminium Alloys.

Sl. No	Alloys
1	1050
2	1060
3	1100
4	1199

Some List of Aluminium Alloys of the 2000 Series

Table 4: Shows the 2000 series of Aluminium Alloys.

Sl. No	Alloys
1	2014
2	2024
3	2090
4	2124
5	2195
6	2219
7	2324

Some List of Aluminium Alloys of the 3000 Series

Table5: shows the 3000 series of Aluminium Alloys.

Sl. No	Alloys
1	3003
2	3004
3	3102

Some List of Aluminium Alloys of the 4000 Series

Table 6: Shows the 4000 series of Aluminium Alloys.

Sl. No	Alloys
1	4041
2	4043

Some List of Aluminium Alloys of the 5000 Series

Table 7: Shows the 5000 series of Aluminium Alloys.

Sl. No	Alloys
1	5005
2	5052
3	5059
4	5083
5	5086
6	5154
7	5356
8	5454
9	5456
10	5754

Some List of Aluminium Alloys of the 6000 Series

Table 8: Shows the 6000 series of Aluminium Alloys.

Sl. No	Alloys
1	6061
2	6063
3	6013
4	6005
5	6060
6	6063

Some List of Aluminium Alloys of the 7000 Series

Table 9: Shows the 7000 series of Aluminium Alloys.

Sl. No	Alloys
1	7005
2	7022
3	7046
4	7068
5	7072
6	7075
7	7050
8	7055
9	7150
10	7475

Table 10: Shows the 8000 series of Aluminium Alloys.

Sl. No	Alloys
1	8000
2	8090

Some List of Aluminium Alloys of the 8000 Series

The Combination of Alloys for Regenerator
Combination of 2195 and 5059

The series of alloys shown in the Tables-3,4,5 are some of the best suited alloys for cryogenic temperatures. In this the 2195 alloy which is a Al-Li alloy, used in Space Shuttle Super Lightweight External tank and the 5059 aluminium alloy which is used in experimental rocket cryogenic tanks. From the above applications of the 2195 and 5059 alloys we can get a new combination of alloy by mixing these to alloys in a proper ratio so that they can withstand the cryogenic temperatures. By this process of mixing these two alloys the Liquid Hydrogen (LH_2) temperature can be bought down below 20K so that maximum efficiency can be obtained at this cryogenic temperature. This combination of alloy by mixing the 2195 and 5059 will not melt very easily. Maximum power can be achieved since aluminium is a very good conductor, so when it is mixed with other metals called alloys its properties gets enhanced and its efficiency gets increased where the power levels of these combination of metals and alloys achieves its maximum value to reach the given target. Since Unhardened 5059 has a yield strength of 23 ksi (23,000 psi; 160 MPa) and ultimate tensile strength of 48 ksi (330 MPa) from −18 to 212 °F (−28 to 100 °C). At cryogenic temperatures it is slightly stronger; above 212 °F (100 °C) its strength is reduced, it can be combined with 2195 because when the lithium is aged it forms a metastable Al_3Li phase with a coherent crystal structure, these precipitates strengthen the metal by impeding dislocation motion during deformation. The precipitates are not stable however and care must be taken to prevent overaging with the formation of the stable AlLi phase. This also produces precipitate free zones typically at grain boundaries and can reduce the corrosion resistance of the alloy. Since the mechanical strengths of both 5059 and 2195 are greater they form one of the best suitable regenerators for cryogenic temperatures in the cryocoolers.

5. Combination of 7075 and 2219

The combination of 7075 and 2219 is right to be used for regenerator constructing material because 7075 is an aluminium alloy with zinc and has very high strength to density ratio, it has maximum tensile strength of about 40000 psi (276 MPa), maximum yield strength of about 21000 psi (145 MPa), so due to its high heat transfer properties like withstanding very high temperatures without corroding by forming thick oxide layers. When this 7075 alloy is combined with 2219 alloy which is an alloy of aluminium and copper which is usually used in space shuttle external light weight external tanks so it shows that it can withstand maximum temperatures without corroding, due to this property of 2219 it can be combined with 7075 alloy to form the regenerators at cryogenic temperatures. As shown in Fig-5 the 2219 alloy's conductivity increases with the increase in temperature. Since aluminium alloys are lighter in weight they will be best suited in space travels.

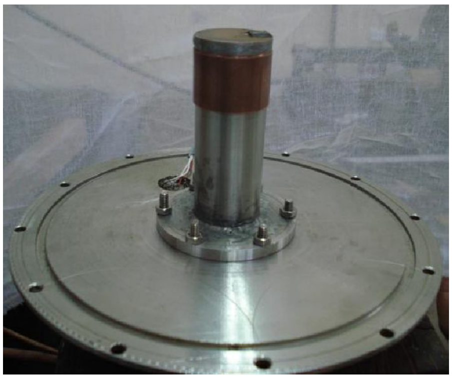

Fig. 6: Shows a regenerator in a Pilse Tube Referigerator

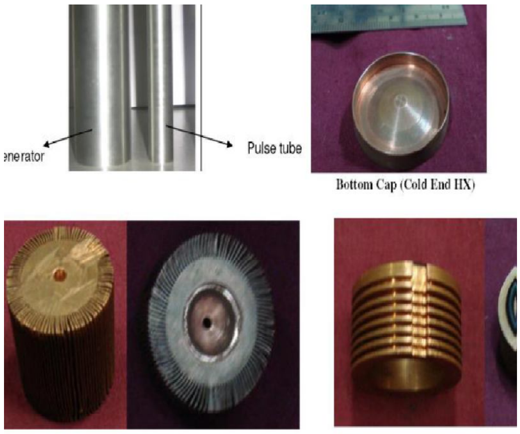

Fig. 7: Shows a co-axial Pulse Tube Refrigerator fabricated parts.

Fig. 8: Shows the regenerator to the top left of the U-shaped material.

6. Conclusion

These combinations of alloys can be used in high proportions in order to keep the regenerator working in very high conditions. So when use the combination of 2195 and 5095 alloys a regenerator can be build at cryogenic temperatures , the temperature of Liquid Oxygen can be bought below the 20K point for its operation in the cryocoolers. Even the combination of the 7075 and 2219 can be bought into manufacturing of the regenerators in the cryocoolers to bring down the temperature of the Liquid Hydrogen below 20K. This can be made a success by using appropriate methods of fabrication. By this method the cryogenic technology can reach a new level in the Aerospace and the Aeronautical Industry.

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