Design and Development of a Heat Recovery Wheel for Low Duty Industrial Applications

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Abstract— This project report proposes a cheap and effective way of designing and fabricating of heat recovery wheel that may be effective to run low duty applications such as motors, compressors. Since the heat recovery wheel has high torque it can be used in nuclear power plants for driving pumps. The design process starts by considering its top level objective and passing these criteria to its sub assembled designs. Finally, the paper proposes outline of theoretical background of heat recovery wheel, working principle, various design parameters, innovative use of fabrication works and industrial implementation ways. The design process involves the design of chambers, selection of liquid, amount of heat addition, heat rejection, and many more. These sub design parameters help in finding out head in which the cycle can be operated. The torque that can be obtained from our model is also calculated. The paper also proposes the failures in the first two designs and explains how we arrived at the final design. The fabricated work involves usage of available materials in and around effectively. As a result, final assembly of the engine meets the objective.

Key words: Low Duty Industrial Applications, Heat Recovery Wheel

I. Introduction

In recent years usage of fuels and energy are being increased, this results in crisis for decades. All the mainly used fuels such as coal and petroleum are non renewable and exhaustible.These fuels are the main pollution causing agents and the chief contributors of carbon dioxide, carbon monoxide, methane etc. More importantly they are starting to become depleted. The shortage of fuels is becoming serious year by year. It is very difficult to survive in the future when these sources are completely depleted. The need to overcome this energy crisis necessiates the requirement of alternative fuels that would successfully replace these depleted resources and meet our ever growing energy demands and needs. Scientists are looking for additional feasible sources of energy in their wide range effects to assure adequate energy supplies. The different ways proposed the ways to reduce the existing energy and to reuse the waste energy. The heat recovery wheel can run without fuel by using low grade energy. This energy source can be anything like the flue gas from the industries, solar energy, etc. There are various heat engine designs and models that can readily use available solar heat for operation. The famous device among this is the dippy bird design which is considered as a novelty item. The heat recovery wheel works in the same principle as the dippy bird

II. Working Principle

The heat recovery wheel works on the principle of pressure difference that exists between the chambers. It consists of series of sealed chambers (even in number). Diametrically opposite pairs of chambers are connected by tubes. The heat is supplied at the bottom of the chamber, by an isothermal water bath container, where the fluid in it changes its state from liquid to vapor. During vaporization only part of the liquid gets converted into vapor and remaining liquid moves to the upper chamber due to the pressure exerted by the vapor. The liquid fluid that is forced up to the upper tank causes an imbalance in the weight of the system. This makes the wheel to turn by gravity. The chamber which has the vaporized fluid moves up and then changes again to the liquid state as it comes in contact with the atmosphere. This again comes in contact with the water bath and the process continues, where by the heat is converted to mechanical energy. Finally, after having a 180 degree rotation, the two chambers exchange their positions, and the process repeats. In the Minto engine with several such pairs, this process itself repeats several times in each revolution of the engine. This can work with a small temperature difference. The CATIA model which helps in understanding the operation of heat recovery wheel is shown in fig 1.

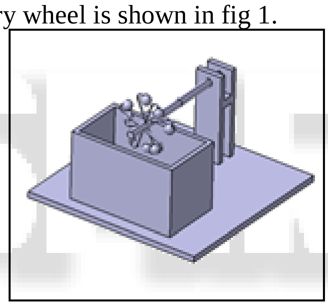

Fig. 1: Working of Heat recovery wheel.

III. Design and Fabrication of Heat Recovery Wheel

The design process involves the design of chambers, selection of liquid, amount of heat addition, heat rejection and many more.

A. Selection of Fluids

The fluid should possess the following properties:

1) It should have high vapor pressure so that it pushes the non-vaporized liquid effectively to the top chamber.
2) It should have low boiling point so that it runs with any form of energy.
3) It should possess low enthalpy of vaporization (Δh_{vap}).
4) It should have low specific heat.
5) It should have high liquid density

We can also use some Nanoparticles together with the fluid for effective heat transfer.

The table which shows the properties of various fluids is given below.

Liquid	Boiling Point (°C)	Latent Heat of Vaporization (H_{Fg})	Vapor Pressure (Bar)	Density (Kg/M^3)	Specific Heat (C_p)
R-11	23.71	181.358	1.0605	1479.328	0.0835

N-Pentane	36.1	460.345	0.0057	626.00	0.167
Propane	42.11	452.59	8.587	580.88	0.0654
Dichloro Methane	39.8	330.467	1.685	1325	0.103
Propene	47.62	438.96	10.17	610.06	0.0563

Table 1: Properties of Various Fluid

From the above list of properties, we have found that Dichloromethane is suitable for the cycle. The properties of dichloromethane are listed:

– Boiling point: 39.6^0C
– Density: 1300kg/m^3
– Specific heat: 1.2kJ/kg K
– Latent heat of vaporization: 330kJ/kg

B. Selection of Chamber Material

The material to be selected for the chamber should have the following characteristics:

1) Extended surfaces should employed to facilitate effective heat transfer.
2) The tanks together with the tubes should be hermetically sealed to prevent the vapor from escaping out.
3) The material used for tanks should have high thermal conductivity.
4) It should have low power loss due to weight
5) It should have high surface to weight ratio

Selection of chamber plays a vital role in conductivity of heat from the source to the fluid.

The table which shows the thermal properties of various material is shown below.

Material	Density (Kg/m^3)	Thermal Diffusiviy (m^2/S)	Specific Heat (Kj/Kgk)	Thermal Conductivity (W/Mk)	Machinability
Aluminium	2707	84.18e-6	896	204.2	Poor
Copper	8954	112.34e-6	383	386	Excellent
Steel	7753	9.70e-6	486	36.3	Good
Glass	2500	3.4e-7	753	1.23	Poor

Table 2: Thermal Properties of Various Material

Glass has been chosen because of its low power loss due to weight, even though its thermal conductivity is low. Another reason for selecting glass is to make the process transparent

C. Selection of Shape of the Chamber

Shape of chamber plays a dominant role in heat transfer, in order to have a maximum heat transfer and less power loss due to the weight of the chamber. For the above requirement elongated circle shape is preferable. First we have chosen spherical shape. But after finding the mistakes in it, we switched over to this shape

D. Calculation of Working Head

To find the maximum height,

$$P_{gravity} + P_{top} < P_{bottom}$$

P_{top} = vapor pressure at the top of the chamber.
P_{bottom}=vapor pressure at the bottom of the chamber.
$P_{gravity}$= pressure due to gravity.
P_{top} and P_{bottom} can be measured or calculated from the Antoine equation which depends on the temperature.
$P_{gravity} = F_{gravity}$/area.
$F_{gravity}$ = mass x gravity
Mass = density x volume

$$F_{gravity} = \rho \text{ x v x g}$$
$$\text{Volume} = \pi \text{ x } r^2 \text{ x H}$$

Where,
r = radius of the cylindrical tube.
H= height of the tube.

$$F_{gravity} = \rho \text{ x } \pi \text{ x } r^2 \text{ x H x g}$$

$P_{gravity}$ = $F_{gravity}$/area = ρ x H x g

$$P_{gravity} < \frac{(P_{bottom} - P_{top})}{\rho \text{ x g}}$$

For dichloromethane,
Vapor pressure at 26.9°C = 62.1kPa
Vapor pressure at 40.7°C =101.3kPa

$$H < \frac{(101.3 - 62.1) \text{ x } 10^3 \text{ N/m}^2}{1325 \text{ kg/m}^3 \text{ x } 9.81 \text{ m/s}^2}$$

H < 3m

But as for our economic considerations, complexity in fabrication and for achieving better efficiency we have planned to operate the fluid for the height of 0.3m

E. Minimum Pressure Difference Needed

Minimum pressure difference needed:
=Density x gravity x height to which the fluid is pumped (ρgh)
=1300kg/m^3 x 9.81 m/s^2 x 0.30m
=3825.9kg/ms^2
=3.82 kPa<< (P(bottom)-P(top))

F. Reas On For First Design's Failure

The CATIA model of our first design is shown in fig 2.

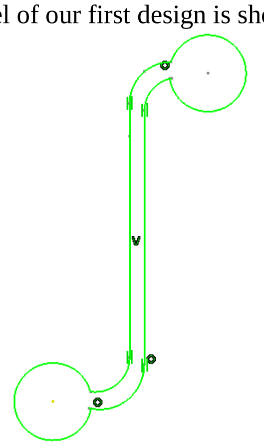

Fig. 2: 2D View Of Initial Design

On looking onto the properties of the materials,we have chosen glass for the chamber.we thought of using spherical shaped chamber.The problems that we faced with this design are:

1) Vapor got escaped from the chamber instead of pushing the liquid after some level
2) The cork which is provided for filling the liquid created a weight imbalance in the system

G. Reason for Second Design's Failure

Having understood the problems with the first design,we designed the second model which rectifies the first problem in design 1.But again we had the following problems in the second design

1) The cork created a weight imbalance in the system.
2) We couldn't create complete vaccum in the system,so that the air in the top chamber resisted the liquid flow from the bottom,thus increasing the net pressure in the system.

The glass material couldn't withstand this pressure,which ultimately resulted in the crack generation and failure.

The CATIA model of the second design is given in fig 3

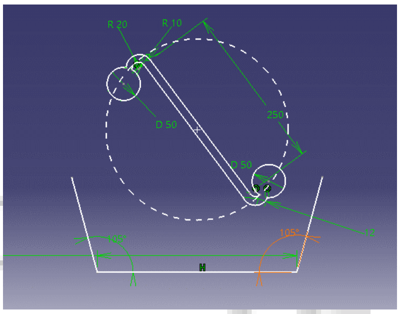

Fig. 3: 2D View of Second Design

The physical model of the second design is shown in fig 4:

Fig. 4: Second Model

H. Final Design

After sometimes we understood that the elongated circle shape is having more surface area than the sphere.Also,we rectified the mistakes that we have done in the first two designs.

The CATIA model for the final design is shown in fig 5:

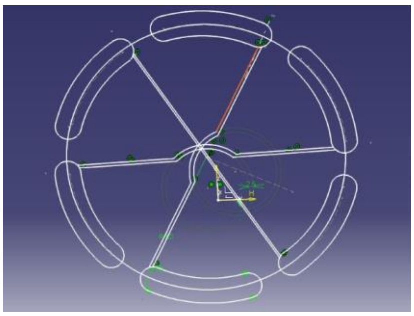

Fig. 5: 2D view of final design

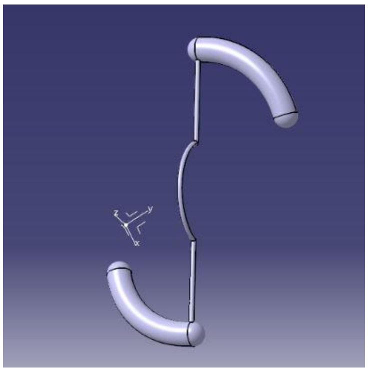

Fig. 6: Catia model of final design

The final model of the project after the assembly is shown in fig 7:

Fig. 7: Working prototype

I. Thermal Calculations

Liquid density of dichloromethane
ρ_{liq} at 25.1°C=1315.17 kg/m^3
38.8°C=1283.04 kg/m^3
Average liquid density ρ_{avg}=1300 kg/m^3
Average vapor density ρ_{vap}=3.54 kg/m^3
Mass of the refrigerant in one chamber,m=25gm
Heat energy needed to vaporize this amount(latent heat) =m h_{fg} =0.02X330kJ =6.6kJ
Initial heat supplied(h_f)=mc_pdT.
=0.02 x 1200 x14
=0.336 kJ
Total heat supplied = h_f + mh_{fg}
=6.6 + 0.336
=6.936kJ (for one chamber)

J. Heat Transfer Calculations

Prandtl's number =(μc_p)/k
Pr =4.5 (at 45^{0}C)
Grashof's number(Gr)=($g\beta\Delta TL^3$)/γ^2
=9.81 X(1/310.5) X 5 X(0.01)^3 (0.2 x10^-6)^2
=3.949 x 10^8
Gr.Pr =1.777 x10^9
Nu =2+0.5(Gr.Pr)^0.25
Nu =104.6
Nu =(hx)/k
h =(45.53 x0.08) 0.01

K. Energy Output

Torque =force x radius
Force =pressure difference(Δp)x cross sectional area(A)
Torque =40000 Pa x 314 x 10^-6mm^2 x 0.15mm =1.885 Nm

The figure which explains the torque produced by the engine is shown in fig 8:

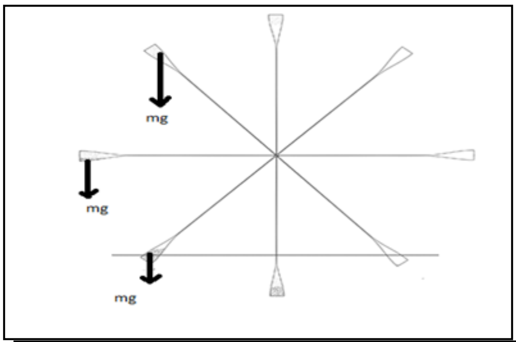

Fig. 8: Schematic of Torque generation

L. Fabrication

Both the chamber and the connecting tubes were fabricated using glass blowing technique.We have used borosilicate for this purpose.It can withstand the maximum temperature of about 100 degree celsius ,which is within the range.

M. Cost Estimation

The table showing the cost of various components used in the project is given below

S. No	Items Purchased	Cost Per Unit (Rs)	No. of Units Purchased	Total Cost (Rs)
1.	Glass chamber (First design)	800	1	800
2.	Glass chamber (Second design)	700	3	2100
3.	Glass chamber (Final design)	330	3	990
4.	Refrigerant (methylene dichloride)	354	1	354
5	Refrigerant (diethyl ether)	500	1	500
6	Aluminium shaft	50	1	50
7	Ball Bearing	15	2	30
8	Stand	180	2	360
9	Other accessories			250

Table 3: Cost Estimation for the Project

Total cost for the project=Rs.5434.

IV. Results and Discussion

Having understood the problems with the first design,we designed the second model which rectifies the first problem in design 1. But again we had the following problems in the second design

1) The cork created a weight imbalance in the system.
2) We couldn't create complete vaccum in the system,so that the air in the top chamber resisted the liquid flow from the bottom,thus increasing the net pressure in the system.

The glass material couldn't withstand this pressure,which ultimately resulted in the crack generation and failure.

After sometimes we understood that the elongated circle shape is having more surface area than the sphere. Also, we rectified the mistakes that we have done in the first two designs.

V. Conclusion

Inspite of glass having low thermal conductivity,we have used it in order to make the process transparent.Many further improvements can be made to this engine.copper which has very high thermal conductivity can be employed for the chamber,which will increase the performance of the heat recovery wheel. Thus, the heat recovery wheel is a non-polluting heat engine that can utilize wasted heat from various sources and systems. It does not require fossil fuel for its running, making it environment friendly. In an internal combustion engine, only the gases get heated up in each cycle. With the heat recovery wheel the tanks and the liquid (and to a lesser extent, the pipes between) all get heated and cooled each cycle.

It will never be as efficient as other engines but other engines can't run very well on the small temperature difference like the Minto wheel. As of today, the models of the engines created produced low rpm with limited torque, making it impractical for power generation or for other minor load requirements. Hence it can be considered as an experimental heat engine which can rotate on wasted heat, which otherwise will be lost. The design of this engine should be taken for research and efforts to improvise the speed and torque so that it can be used for various purposes

The various applications of the heat recovery wheel are:

1) The heat recovery wheel can be used to drive low power compressors.
2) It can also be used as an alternate for motors in the industries by utilizing waste heat as a heat source. (series of such engines can be employed).
3) It can be used in nuclear power plants for driving pumps.

We can also use NANOPARTICLES together with the fluid for an effective heat transfer.

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