THE ICY RIDER: A VEHICLE DRIVEN BY FREEZING WATER

*Mohamad Kharseh¹, Mohammed Al-Khawaja²
¹² Qatar University, Mechanical & Industrial Engineering Department, Doha, Qatar

ABSTRACT

The Icy Rider is a small vehicle driven by the expansion pressure of freezing water. Its driving energy is generated by freezing a confined water volume of 0.027 m³ until a pressure of 25 MPa occurs. Generated energy is extracted by a simple hydraulic system. With a total weight of 200 kg (incl. driver) the Icy Rider reaches a speed of 70 km/h over a maximum driving distance of 400 m. Media showed great interest at the time of its design in 1985 and according to ratings the Icy Rider was watched on TV by more than 100 million viewers. Because of recent interest in the Icy Rider, the current paper describes its operating principle and theoretical basis. It is shown that the energy utilized by the Icy Rider is 6.5 Wh. Since this energy is extracted during about 25 seconds it means a power of 1 kW. A well designed Icy Rider could potentially utilize considerably more energy and reach considerably greater velocities.

Keywords: Ice Physics, Pressure Volume Work, Thermodynamics Processes

INTRODUCTION

The Icy Rider is a small go-cart looking vehicle, as shown in Fig.1, driven by the pressure-volume work (PVW) of freezing water. It was a result of Nordell’s hobby research in 1985, at the Division of Water Resources Engineering, Luleå University of Technology (LTU), Sweden. The combined effect of the volume expansion of freezing water and its small compressibility create very high pressure (Fig.2), which is used here to generate energy.

The Icy Rider has a weight of ~200 kg including the driver and is driven by 0.027 m³ of water. The PVW is transferred by a hydraulic system shown in Fig.3. This way the Icy Rider reaches a maximum speed of ~70 km/h over a maximum driving distance of ~400 m. Because of lack of funding the Icy Rider was made as inexpensively as possible and the extractable energy is therefore not used efficiently.

At the time of its creation the Icy Rider was received great interest in national and international media. Information on the Icy Rider was published in newspapers around the world and
on national and international TV shows such as “BEYOND 2000” on Discovery Channel and “NARUHODO the World” on National Japanese TV (NARUHODO, 1988). According to ratings the Icy Rider was watched on TV by more than 100 million viewers. Although the Icy Rider became known world wide, nobody ever claimed that something similar had been made elsewhere.

Fig. 1: The Icy Rider in 1985.

Except for a limited study on possible applications of the energy extraction technique used in the Icy Rider (Nordell, 1989), no article has been published to describe its theoretical basis. Because of a renewed interest in the Icy Rider its principle and theory are described in the current paper.

THEORETICAL OVERVIEW

Ice Physics

Very few measurements exist of the pressure-melting temperature of normal ice (1h). In early studies (Bridgman, 1912, Tammann, 1903, Tammann, 1910)(Fig. 2) the ice was kept under constant temperature while an increasing pressure was applied. The melting-pressure point was reached when a sudden melting occurred. Nordell (Nordell, 1990) used a different measurement approach. A water-filled container of great strength was placed in a freezer at constant freezing temperature. This way the applied pressure was generated by the freezing water itself. Pressure and temperature were measured in the ice water mixture and the melting-pressure point was reached when the pressure increase stopped. These measurements were repeated for a range of constant temperatures.

Fig. 2: Pressure-melting temperature of ice (Nordell, 1990).
Fig. 2 shows that the maximum pressure of 220 MPa is obtained at a temperature of -22°C. At lower temperatures a new type of ice is formed, in which the pressure decreases with even lower temperature.

ENERGY EXTRACTION

Fig. 3 illustrates the hydraulic system used to extract the PVW of freezing water. The system consists of a water-oil container (WOC), a gas-oil container (GOC) which acts as a pressure accumulator, an oil collector (OC), a hydraulic motor and two valves those are used to control the flow of oil between the components. The operation cycle involves the following processes:

1. **Charging process** (Fig3-a): valve A is open and valve B is closed. Due to the freezing of water in WOC oil will be pushed into GOC.
2. **Storing process** (Fig.3-b): valve A is closed i.e. all valves are closed at this moment and pressurised gas can be stored until it is needed.
3. **Extracting process** (Fig.3-c): valve B is opened (valve A is still closed) and the oil flows through a hydraulic motor generating energy, E. The used oil is collected in OC.
4. **Sucking process**: by opening valve A (valve B is still open) and melting the ice in WOC, oil returns to WOC.

![Fig. 3: The hydraulic system of the Icy Rider divided into three parts: a) charging, b) storing and c) extraction modes. WOC = Water-Oil Container; GOC = Gas-Oil Container (Pressure accumulator); OC = Oil Collector; HM = Hydraulic motor](image)

The pre-set gas pressure in the GOC is $P_1$ at the temperature of the cold source, while the final oil pressure is $P_2$. The volume expansion of the freezing water forces the oil out of the WOC into the GOC. Consequently, the gas pressure increases from the initial $P_1$ to $P_2$. When the GOC is fully charged and all water has turned to ice, valve A is closed and the pressurized oil is stored until it is released by opening valve B and driving the hydraulic motor.

Since the freezing process is slow, the compression process is considered to be isothermal i.e. $T_1=T_2$, while the fast expansion process is considered adiabatic, as shown in the thermodynamic cycle in Fig.4. The performed derivation of thermodynamic processes follows basic rules found in any textbook on thermodynamics (Massoud, 2005).

Based on the first law of thermodynamics the work done by the adiabatic expansion equals the change in internal energy $\Delta U$ of the gas:
Here, $T_2$ and $T_3$ are the temperatures of the gas at the end of the compression and expansion process, respectively; $m$ is the mass of gas (kg) and $C_v$ is the specific heat capacity of the gas at constant volume (J/kg.K), which is defined as:

$$C_v = \frac{R}{\gamma - 1}$$

where, $R$ is the specific gas constant, and $\gamma$ is the adiabatic index of the gas.

Using the adiabatic process rules, Eq.1 can be rewritten as:

$$E = \frac{1}{\gamma - 1} P_1 \cdot V_2 \left( \delta - \delta^\gamma \right)$$

where $\delta$ is a compression coefficient, defined as the ratio of the maximum pressure, $P_2$, to the pre-set gas pressure, $P_1$, i.e. $\delta = \frac{P_2}{P_1}$. The next step aims to eliminate the unknown term $V_2$ from Eq.3. The accumulation of oil in the GOC results in a gradual decrease of the gas volume. When all water has turned to ice, the final gas volume in the GOC becomes:

$$V_2 = V_g - \varepsilon \cdot V_w$$

Here, $V_g$ is the initial gas volume in the GOC, $\varepsilon$ is the volumetric expansion coefficient of the water due to freezing, and $V_w$ is the total volume of water in the WOC. Using the isothermal rule between state 1 and 2, one can write:

$$P_1 \cdot V_g = P_2 \cdot V_2$$

Solving Eq.4 and Eq.5 yields:
\[ V_g = \frac{\varepsilon \cdot \delta \cdot V_w}{\delta - 1} \]  \hspace{1cm} (6)

\[ V_2 = \frac{\varepsilon \cdot V_w}{\delta - 1} \]  \hspace{1cm} (7)

Substituting Eq.7 in Eq.3 yields

\[ E = \frac{\varepsilon}{\gamma - 1} P_1 \cdot V_w \cdot \frac{\delta - \delta^{1/\gamma}}{\delta - 1} \]  \hspace{1cm} (8)

The extractable pressure volume work, E, of the gas pressurized by the freezing water is then given by Eq.8. For the Icy Rider and its specific working conditions (\( \varepsilon = 9\% \), \( V_w = 0.027 \text{m}^3 \), \( V_{oil} = 0.003 \text{m}^3 \), \( V_g \) (initial gas volume) = 0.003 m\(^3\), \( P_1 = 10 \text{MPa} \), \( P_2 = 25 \text{MPa} \) and air as the working gas) the extractable energy is 6.5 Wh. Since the extracted energy was used during 25 seconds, i.e. the duration of the ride, it means that the mean power was about 1 kW, see Fig.5. The way the Icy Rider was built the pressure at the end of the freezing process will not be greater than the maximum allowed pressure (25 MPa) at any freezing temperature.

![Fig.5: Power of the Icy Rider as a function of extraction time.](image)

**DISCUSSION AND CONCLUSIONS**

Performed analysis gives extracted energy from the pressure volume work (PVW) of freezing water as demonstrated in the Icy Rider. Since this PVW compresses the gas of the pressure accumulator isothermally, added energy is lost to the surrounding as thermal energy. Consequently, no energy is added to the system. However, the energy quality or the availability of the gas has increased, i.e. its entropy has been reduced.

- The Icy Rider is driven by energy (6.5 Wh) extracted from 0.027 m\(^3\) of freezing water.
- The short duration of the ride (~25 s) means that a power of 1 kW is generated.
- Minor changes of the Icy Rider would improve its performance.
  - By changing the working gas from air to CO\(_2\), i.e. changing \( \gamma \) from 1.4 to 1.3, increases extracted energy from 6.5 Wh to 7.1 Wh.
By increasing the preset pressure from 10 MPa to 24 MPa for the same maximum allowed pressure (P2=25 MPa) the generated energy would increase to 11.7 Wh. This change, however, requires a larger gas volume.

A better hydraulic motor and a larger pipe diameter would not increase extracted energy but result in a considerable power increase, see Fig.5.

- By modifying the design of the icy Rider it would be possible to achieve a considerable increase of extractable energy and powers from freezing water. This would include new applications of the ice energy.
- Since the maximum freezing pressure of water is 220 MPa at -22C the components of the system must be made to manage the occurring forces.
- In cold regions the pressure volume work of freezing water could be used to generate high quality energy from low quality thermal energy.
- The main benefit of such systems is not the amount of generated energy, but the possibility to achieve very high power.

ACKNOWLEDGEMENT

We thank Assistant Professor Anthony Zander, University of Adelaide, for his valuable comments on performed work.

REFERENCES

4. NORDELL, B. 1989. Prestudy of possible ice energy applications (Förstudie av isenergins användningsområden). Luleå: Lulea University of Technology.