

# Analysis on sealing performance of piston rings used in the liquid hydrogen pump

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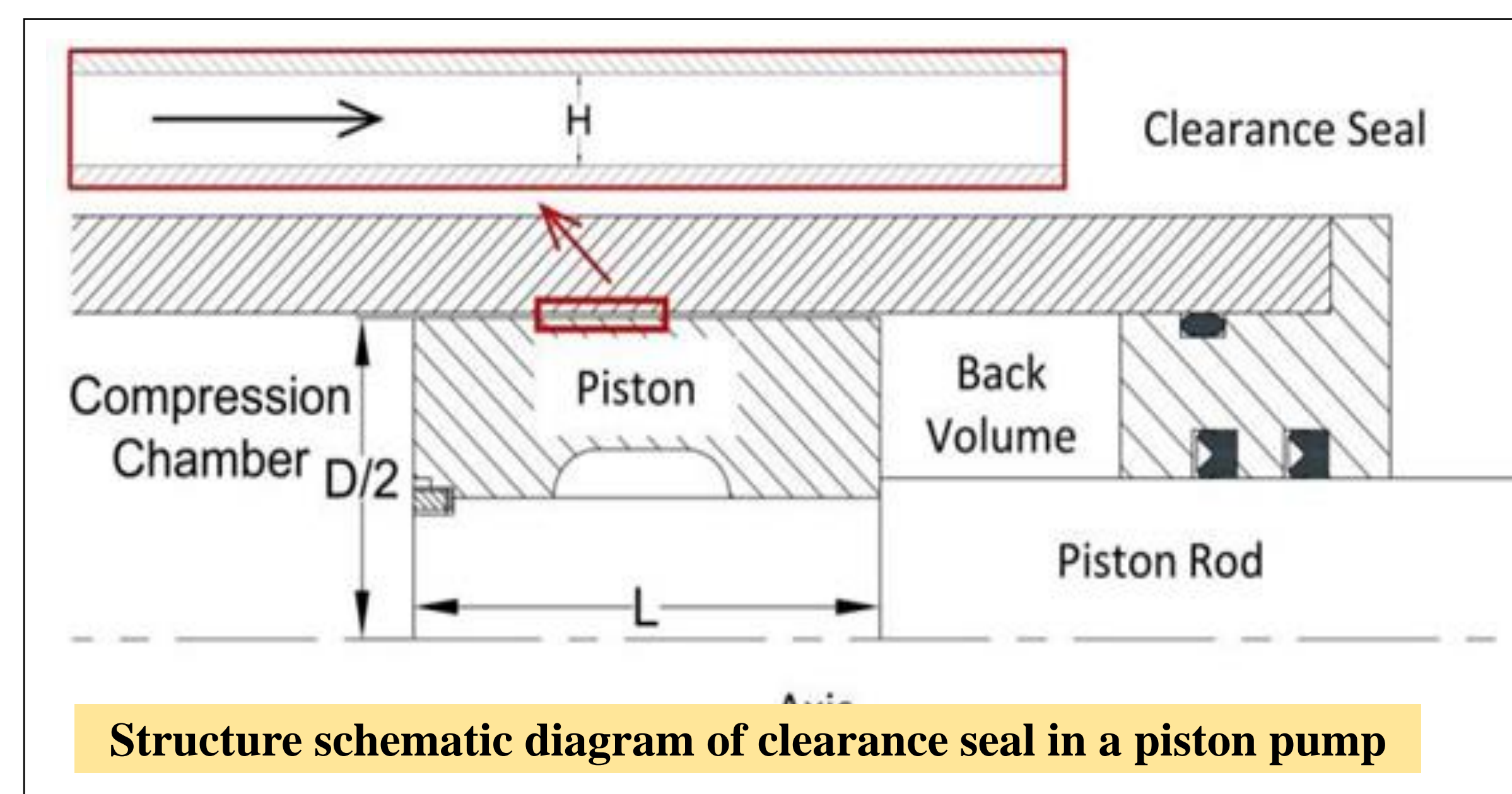
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## Abstract

The sealing structure has a significant impact on the performance of high-pressure liquid hydrogen reciprocating pumps. Piston ring sealing is one of the significant sealing methods employed in such pumps. This paper establishes a leakage calculation model for the piston ring sealing structure in high-pressure liquid hydrogen reciprocating pumps. And the impact of different dimensions on the leakage rate is analyzed and discussed. This work provides a theoretical foundation for the design of liquid hydrogen pumps.

### Clearance seal



Structure schematic diagram of clearance seal in a piston pump

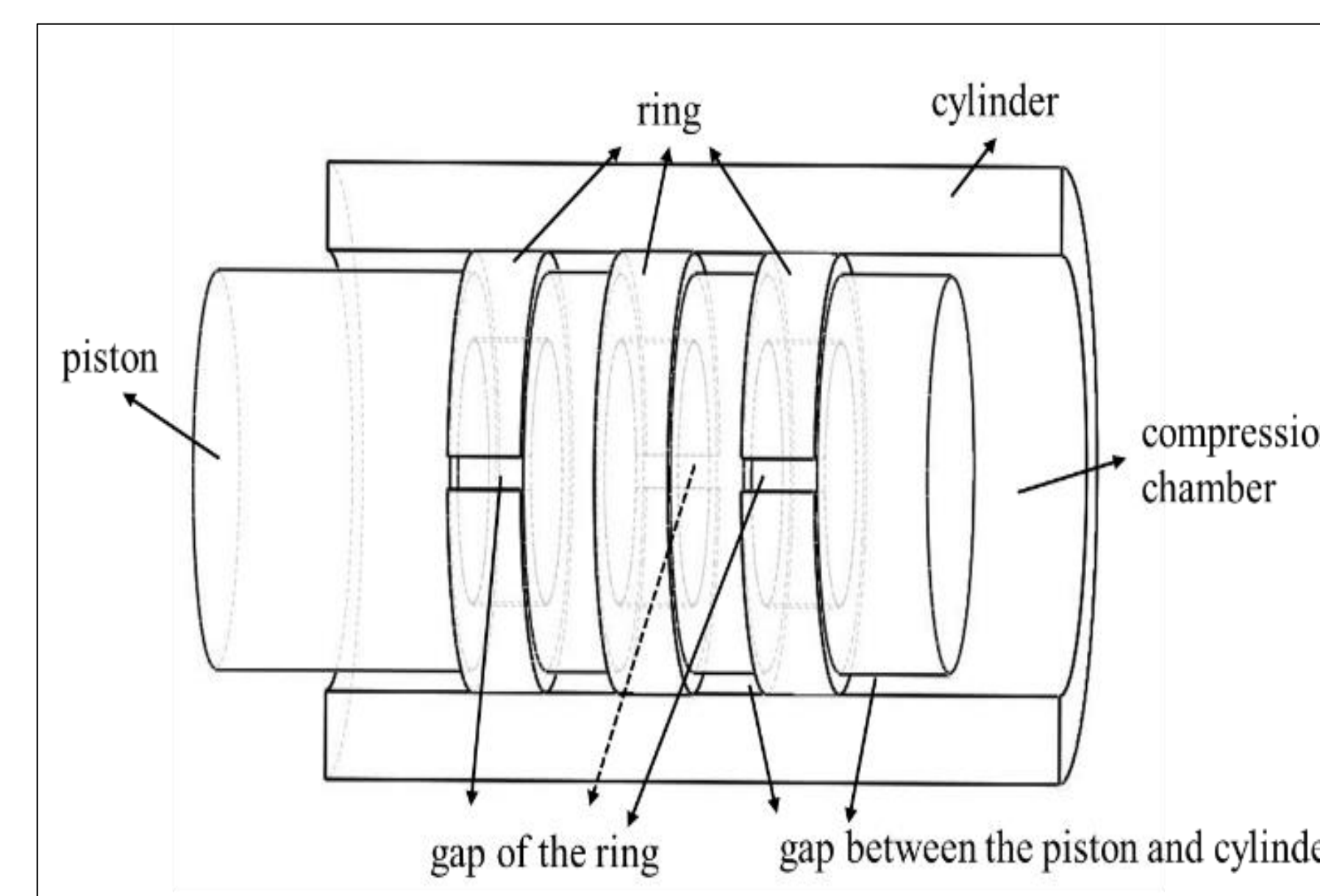
leakage flow rate  $q = \frac{\pi D H^3}{12 \mu L} \Delta p$

#### The leakage flow rate of the clearance seal for different fluid

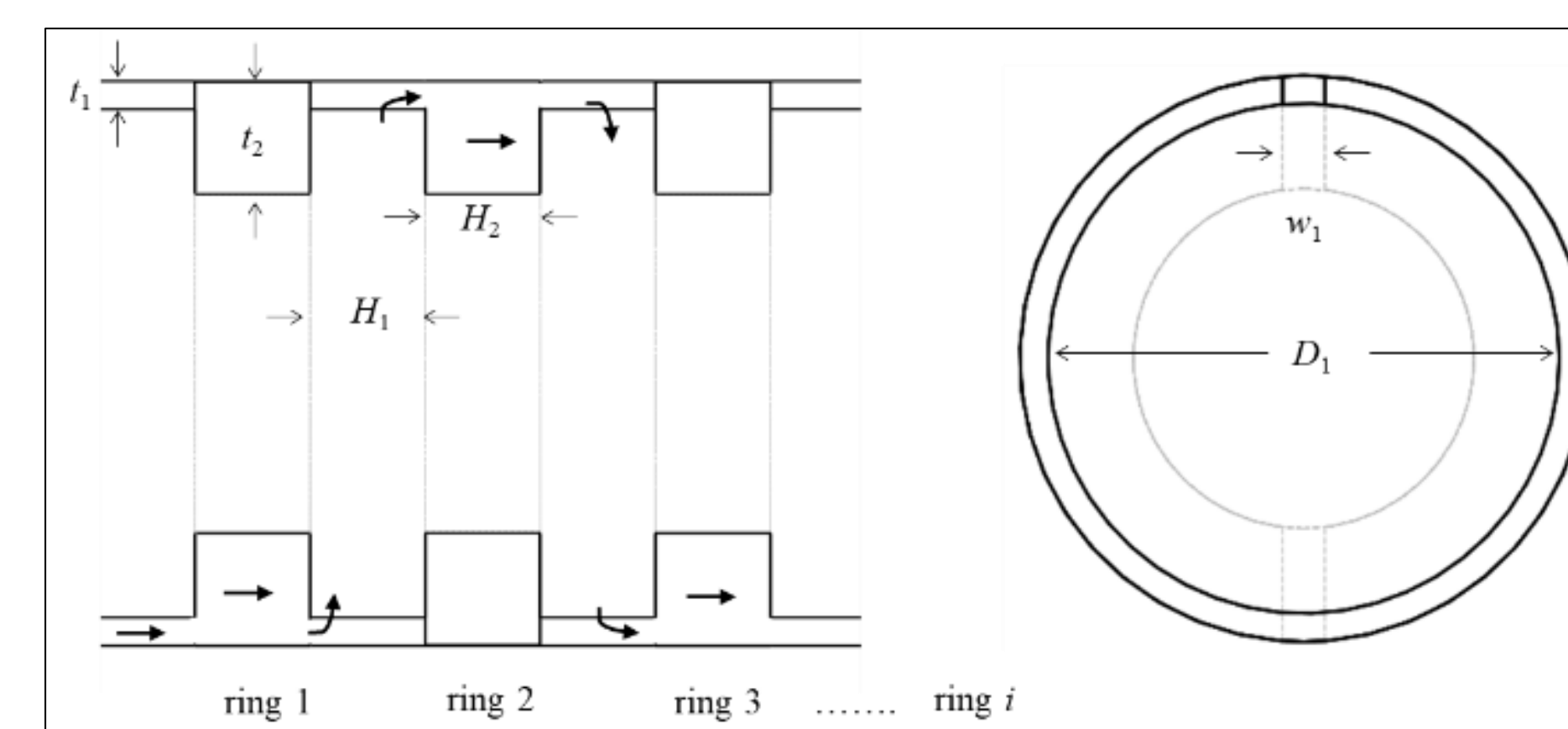
	Hydraulic oil	Liquid nitrogen	Liquid hydrogen
Viscosity ( $\mu\text{Pa s}$ )	30000 (300K, 110MPa)	197 (110K, 110MPa)	36 (55K, 110MPa)
Leakage flow rate (L/min)	3.24	493.11	2698.43

- the Leakage flow rate is 823 times used in than Liquid hydrogen that used in the hydraulic systems
- labyrinth seal can reduce the leakage rate by 60%-70% compared to the clearance seal (Ren, Presented at ICEC29-ICMC2024)
- piston-cylinder ring seal pair structure is needed for a high-pressure liquid hydrogen reciprocating pump

### Piston rings seal



Three-dimensional structure of piston rings seal in a piston pump



Structure schematic diagram of the model in piston rings seal

Bernoulli's equation  $\frac{p_i}{\rho g} + \frac{v_i^2}{2g} + z_i = \frac{p_{i+1}}{\rho g} + \frac{v_{i+1}^2}{2g} + z_{i+1} + h_{loss}$

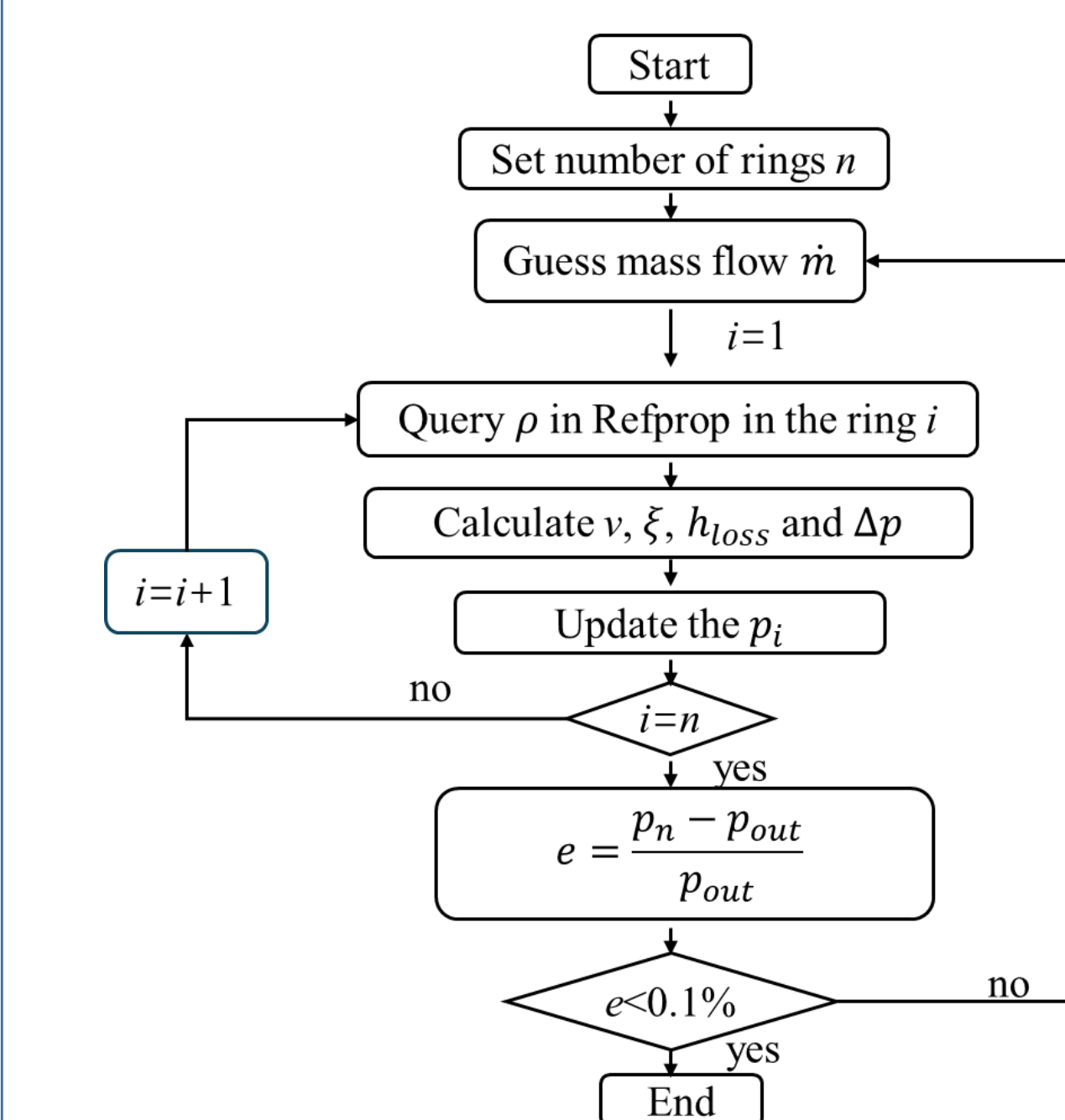
head loss is primarily due to pressure loss

$$\frac{\Delta p}{\rho g} = h_{loss} = \xi \frac{v^2}{2g}$$

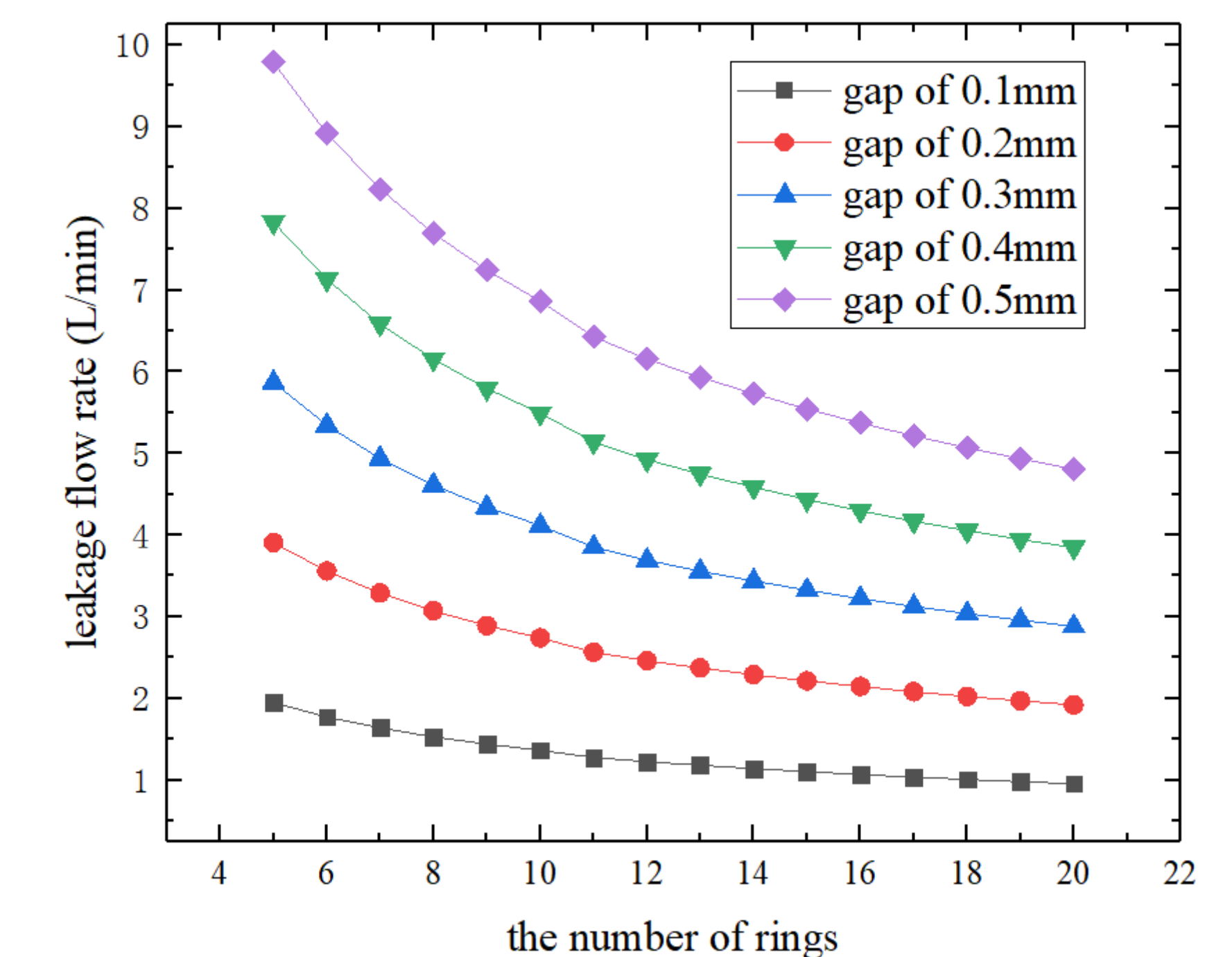
### Calculation and discussion

Assumption:

- density and temperature of liquid hydrogen don't change when liquid hydrogen flow through the gap of every ring.
- heat exchange between liquid hydrogen and the wall surface occurs when liquid flows through the gap between the piston and cylinder within the adjacent two piston rings.
- pressure in the chamber is stable and keeps in 110 MPa.



Computational flowchart



leakage flow rate with different width of the gap

It infers that piston rings seal can decrease the leakage rate lower than 10 L/min, which is comparable to the leakage rate of hydraulic systems. Besides, the larger the gap of the piston ring, the more pronounced the effect of the number of piston rings.

### Conclusions

- sealing effect of labyrinth seals is poor in high-pressure liquid hydrogen pumps;
- piston rings seal can decrease the leakage rate lower than 10 L/min, which is comparable to the leakage rate of hydraulic systems;
- to ensure the volumetric losses due to the leakage from the rings lower than 10% for a pump with theoretical flow rate 25 L/min, it need ten rings with the gap of the piston ring lower than 0.3mm.