

Purpose

The work presents the design and validation of a novel cryogenic-compressed hydrogen (CCH₂) storage and supply system. This CCH₂ system is designed to operate at the pressure up to 20MPa and temperature down to 20K. It is developed to provide an efficient and stable approach to storage and supply hydrogen for heavy trucks, powered by fuel cell stacks.

Principle of System Operation

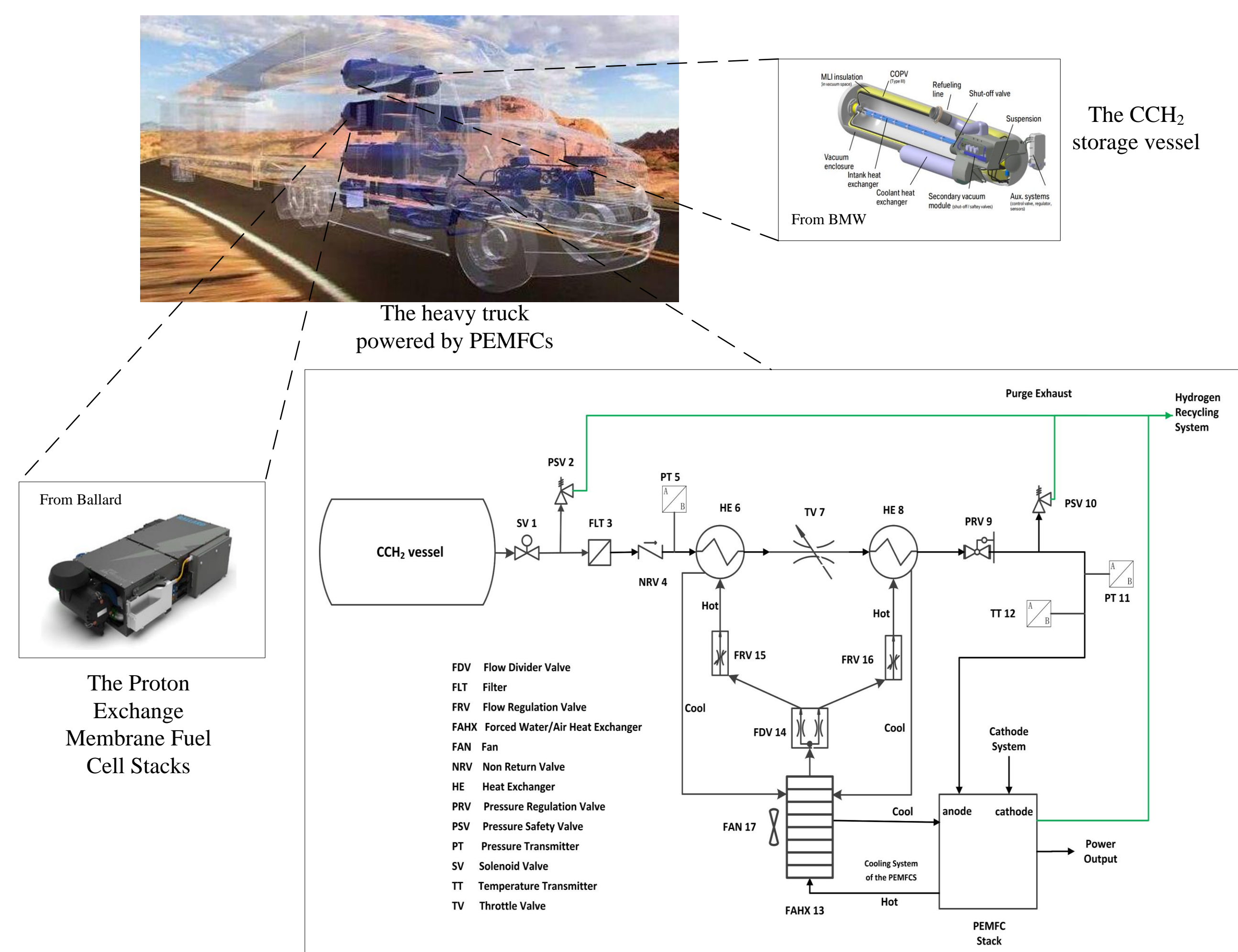


Fig.1 Sketch of the design of this CCH₂ supply system

Results & Discussion

The selection of power for on-board fuel cell stack is the basis of system design, through which the hydrogen mass flow can be determined. The relationship among mass, slope and power has been studied by Matlab and shown in the figures below:

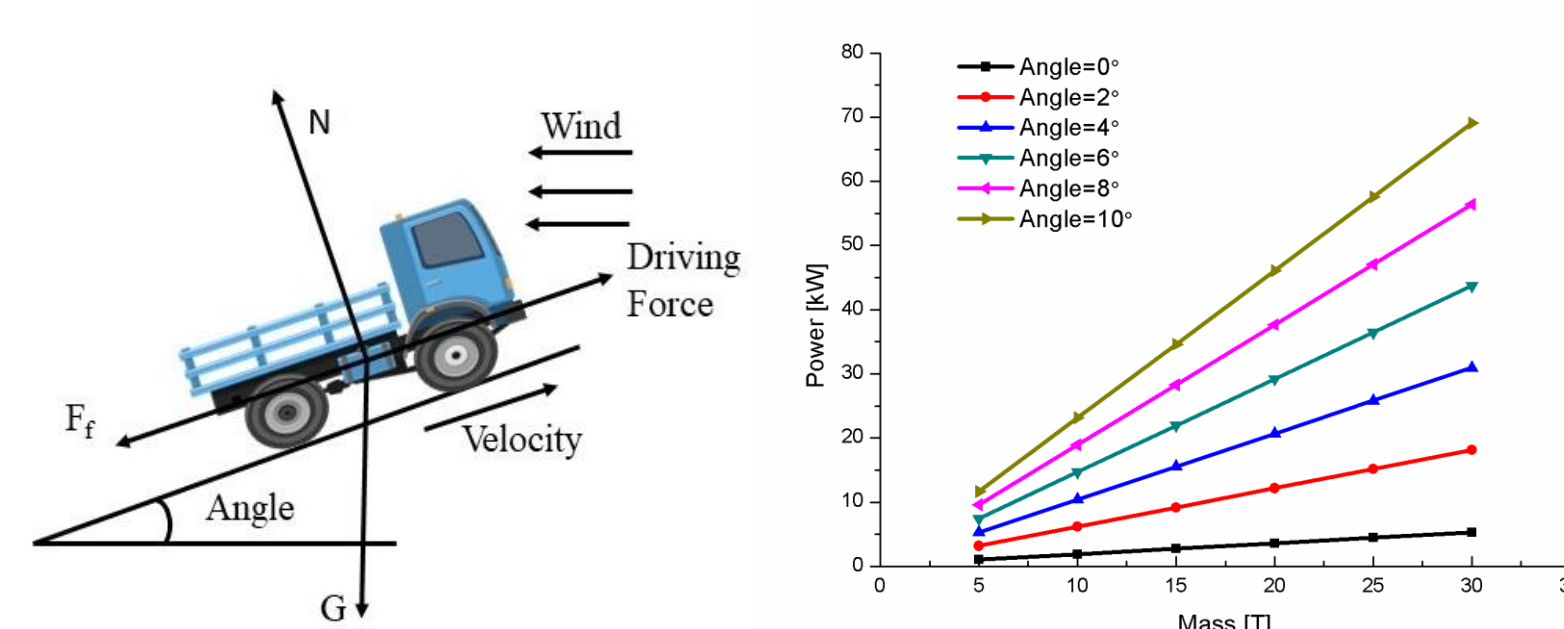


Fig. 2 Schematic diagram of truck power calculation

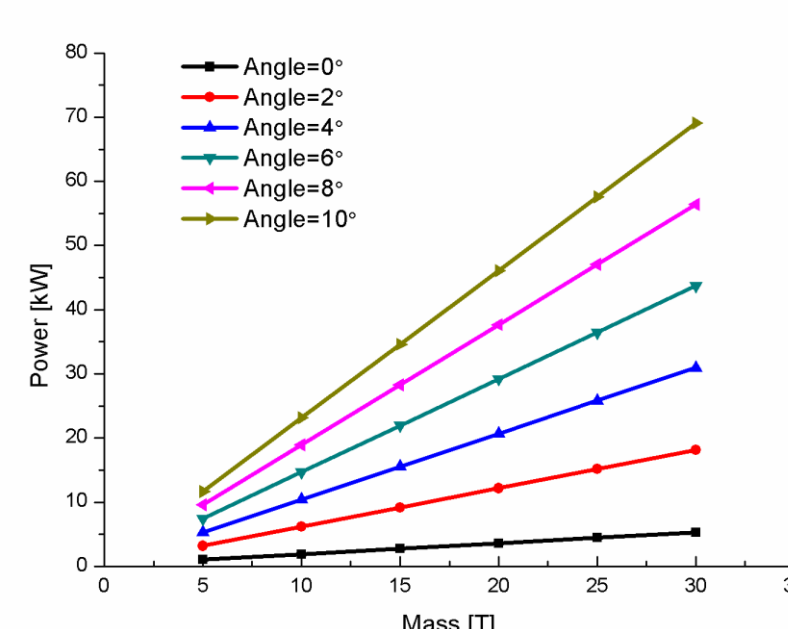


Fig.3 Relationship among mass, velocity and power consumption of heavy trucks(slope=0°)

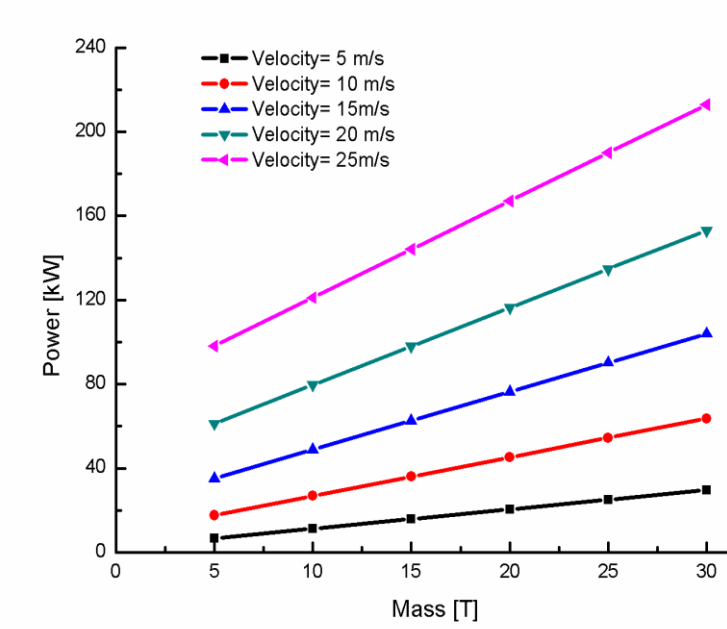


Fig.4 Relationship among mass, slope and power consumption of heavy trucks (velocity=1 m/s)

Taking the 25T (GVWR) truck as an example, it requires 134.70kW to drive the truck whose speed is 20m/s on the flat road and requires 56.43kW when driving on the road with the angle of 10° at the speed of 1 m/s. The former is more than the latter. Hence, the 150kW fuel cell stack has been chose, for satisfying the power requirement and keeping a certain margin. The design maximum mass flow is finally determined, that is, $\dot{m}=3.42\text{g/s}$, with which it is possible to design the following hydrogen supply system.

In the hydrogen supply system, the cryogenic-compressed hydrogen from the storage vessel is about 20 MPa. After passing through the first heat exchanger, the hydrogen flow is heated up and enters the throttle pressure reducing valve to be decompressed to 0.16 MPa.

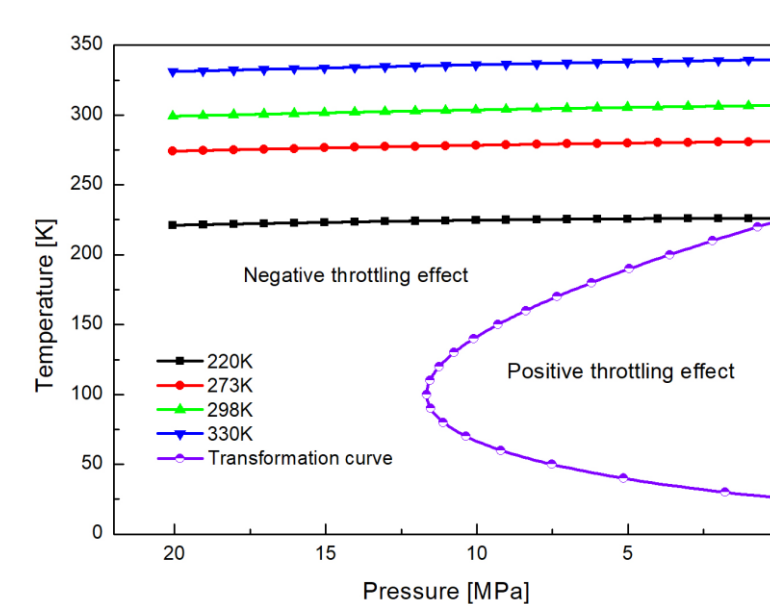


Fig.5 P-T diagram of hydrogen throttling effect

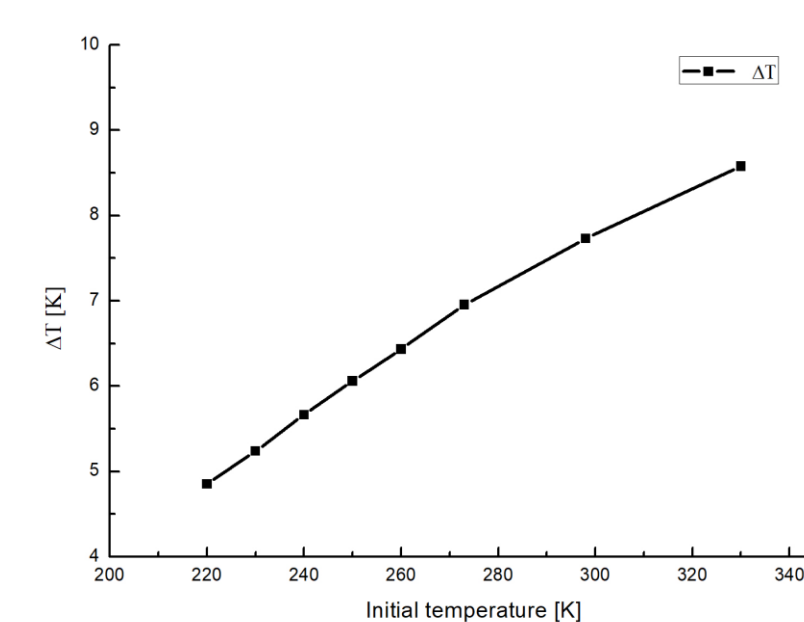


Fig.6 T_0 - ΔT diagram of hydrogen throttling effect

As shown in Fig.5, when the initial temperature is 220K, the P-T curve of hydrogen flow could just avoid the positive and negative throttling effect transformation curve, without conducting the positive throttling effect of hydrogen. As shown in Fig.6, from 220 K to 330 K, with the increase of initial temperature T_0 , the temperature rise ΔT will gradually increase, and the initial temperature T_0 and temperature rise ΔT of hydrogen flow show a linear growth trend.

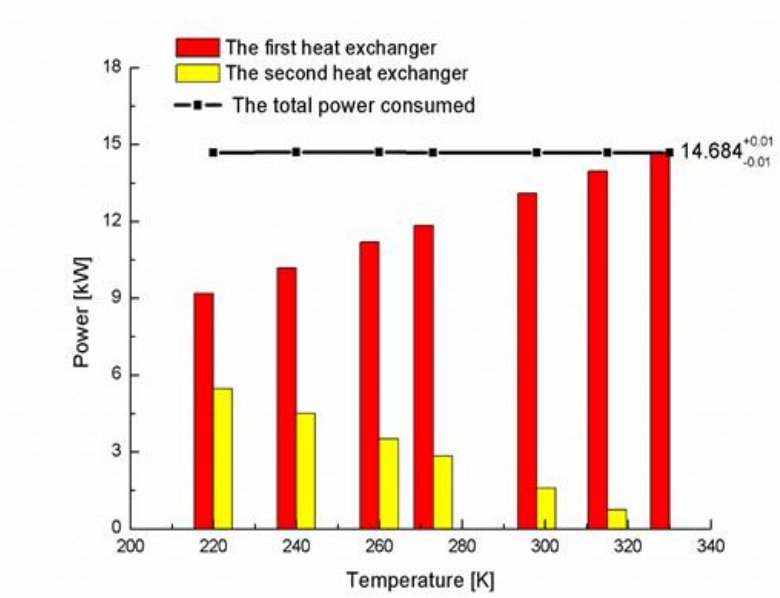


Fig.7 Power consumption of CCH₂ processing system (supposing that the efficiency of three heat exchangers are in an ideal situation, $\eta_1=1, \eta_2=1, \eta_3=1$)

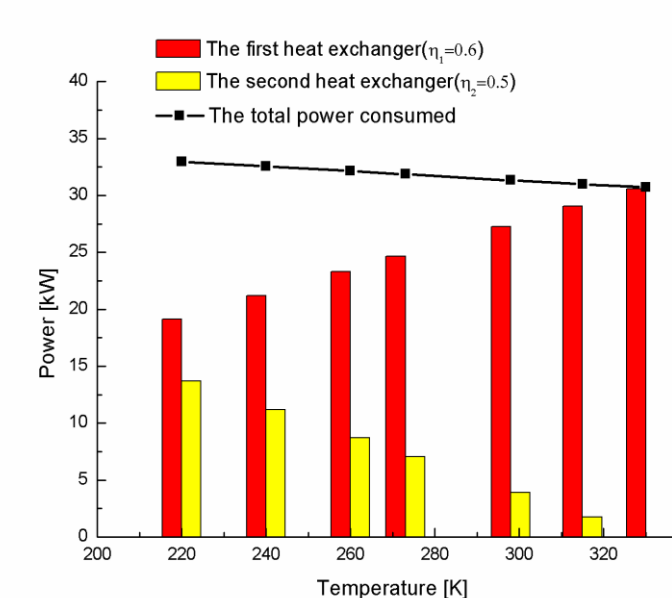


Fig.8 Power consumption of CCH₂ processing system (supposing that the efficiency of three heat exchangers are at low value, $\eta_1=0.6, \eta_2=0.5, \eta_3=0.8$)

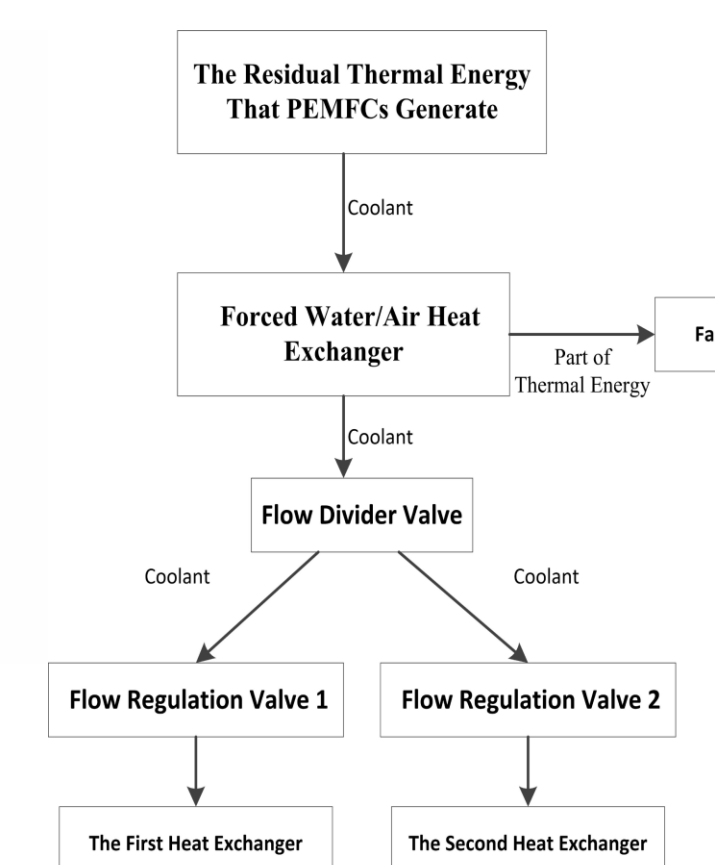


Fig.9 Energy flow diagram of the hydrogen system

From Fig. 7, when the transfer efficiency of heat exchangers is not considered, the power consumed to heat and depress the hydrogen flow of 20K and 20MPa to 330K and 0.16MPa through the heat exchangers and throttling valve is a constant, whatever the specific temperature set by the heat exchangers. When the heat exchangers operate with low thermal efficiency under certain conditions, as $\eta_1=0.6$ and $\eta_2=0.5$ in fig. 8, it is obvious that the power consumption has significant rise. The hydrogen supply system requires approximate 32.83kW if $T_{\text{out}}=220\text{K}$ and 30.58 kW if $T_{\text{out}}=330\text{K}$.

Conclusion

Focusing on the results and data from the calculation, it can be summarized that:

- (1) The selection of PEMFCs mainly depends on the GVWR and designed maximum speed of trucks.
- (2) The negative throttling effect of hydrogen can be reasonably used to maximize the energy utilization rate by heating the hydrogen flow temperature between 220 and 330K through the first heat exchanger.
- (3) The residual heat generated by PEMFCs is sufficient for the CCH₂ requirement.

This study is the first step to get the proper solution for the on-board CCH₂ supply system in heavy trucks. Subsequent studies should focus on the detailed power control for all kinds of driving conditions, the efficiency of heat exchanges and concrete experiment validation.