Design and prototyping of an ionic liquid piston compressor as a new generation of compressors for hydrogen refueling stations

The thesis presents design, modeling, and fabrication of a new compressor technology that involves an ionic liquid piston as a replacement for the solid piston in the conventional reciprocating compressors to compress hydrogen in hydrogen refueling stations. The motivation comes from the need to achieve more flexible and efficient compressors with longer life spans in hydrogen stations. This can eventually lead to a lower hydrogen delivery cost and faster penetration of hydrogen fuel cell vehicles into the market.

A thermodynamic model simulating a single-compression stroke is developed to investigate the heat transfer phenomena inside the compression chamber; the system performance is evaluated, followed by the design process. The model is developed based on the mass and energy balance of the hydrogen, and liquid bounded by the wall of the compression chamber. Therefore, at each time step and positional node, the model estimates the pressure and temperature of the hydrogen and liquid, the temperature of the compression chamber wall, and the amount of heat extracted from the hydrogen directly at the interface between the hydrogen and liquid, and through the wall. The results indicate that depending on the heat transfer correlation, the hydrogen temperature reduces slightly between 0.2 and 0.4% compared to the adiabatic case, at 500 bar. The main reasons for the small temperature reduction are the large wall resistance and the small contact area at the interface. Moreover, the results of the sensitivity analysis illustrate that increasing the total heat transfer coefficients at the interface and the wall, as well as compression time, play key roles in reducing the hydrogen temperature. Further optimization and increasing the total heat transfer coefficient at the interface (10000 times) or at the wall (200 times), leads to 22 % or 33% reduction of the hydrogen temperature, compared to the adiabatic case, at 500 bar, during 3.5 seconds compression, respectively.

A suitable ionic liquid is selected as the most reliable replacement for the solid piston in the conventional reciprocating compressors. Ionic liquids are room temperature salts which have very low vapor pressures. The ability to tune the physiochemical properties of ionic liquids by varying the cation-anion combinations is the feature of these liquids that make them as promising candidates to replace the solid piston. However, due to a large number of available combinations for ionic liquids, it is essential to systematically investigate their performance for a particular application and narrow down the final choice. In this regard, certain criteria are determined for our specific application. The roles of the most commonly used cations and anions, as well as the effect of temperature are comprehensively reviewed to identify the most suitable ionic liquids that can fulfill our requirements. Hence, the options are narrowed down to five ionic liquids with triflate and bis(trifluoromethylsulfonyl)imide as the anion choices and three different cation types of imidazolium-, phosphonium-, and ammonium-based as the cation choices. Finally the ionic liquid: 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide is recommended as the best candidate that can be safely used as a replacement for the solid piston in the conventional reciprocating compressors for compressing hydrogen in the hydrogen refueling stations. In addition, the corrosion behavior of various commercially available stainless steels and nickel-based alloys as possible construction materials for the components which are in direct contact with the selected ionic liquids is evaluated. The results show a very high corrosion resistance and high stability for all of the alloys tested in any of the five selected ionic liquids. The stainless steel alloy, AISI 316L, with a high corrosion resistance and the lowest cost is selected as a material for all the components in direct contact with the ionic liquid, in the designed ionic liquid hydrogen compressor. The new compressor consists of three main parts, namely pneumatic, hydraulic, and custom-designed hydraulic to pneumatic transformer, which work together to compress hydrogen. The proposed design addresses the limitations of the current technology and previously designed compressors using the liquid piston concept and ionic liquid, by introducing a custom-designed hydraulic to pneumatic transformer. As proof of concept, a prototype for compression of hydrogen from 100 to 300 bar is built, and a detailed procedure of the design, fabrication, and control of the prototype is described in the presented work.

The new compressor design has high potential to be used as an alternative to the conventional reciprocating compressors in hydrogen refueling stations, as it provides a simpler design with lower manufacturing costs, higher efficiency, much less sliding friction, possibility of internal cooling, higher functional reliability and less maintenance.