Advances in the Research of Heat Pump Water Heaters

Shangli Shan Dandan Wang Ruixiang Wang
Master Master Professor
Beijing institute of civil engineering and architecture, Beijing, 100044
shanshangli@163.com

Abstract: This paper presents the progress of many recently correlative research works on the heat pump water heater (HPWH) and on solar-assisted heat pump water heaters. The advances in the research on compressor development, alternative refrigerant technology for a compressor HPWH are separately summarized. A new study on frosting/defrosting of an air source heat pump water heater (ASHPWH) is also discussed. The trends of some new technologies of HPWH are analyzed.

Key words: heat pump water heater substitution of working fluid structure of tank technologies and development

1 INTRODUCTION

Hunan society has entered into a high-speed development period and energy is widely utilized in many aspects, such as traffic、building and so on. People could furthest transform natural resources into physical product to meet improved physical needs of mankind, however, just at the moment environment and energy problem is emerging. . People begin to pay more attention on how to make use of energy and how to protect environment effectively。

It is stated that energy used to construction activities is up to 40% of the world's total consumption, and live water heating system is the important part of energy-consuming on construction. Being an energy saving product, heat pump water heater (HPWH) get more attention from mankind. Heat pump water heater first emerged in 1950s，it has a rapid development after energy crisis.. Compared with traditional water heater, the advantage of HPWH is self-evident. Firstly, it can utilize abundant natural resources and waste heat, so it can save primary energy sources. Secondly, it can offer not only live heating water but also air conditioning heating water, so energy utilization efficiency is improved. Thirdly, it is very safe when being used, and exhaust gas is not produced. Electricity at night is used to heat water which is stored in tank, so electricity demand can be balanced by HPWH on a certain extend. Being have those prominent advantages, heat pump water heater is studied by many researchers. In many countries heat pump water heater is popular in the market, such as American Japan and so on.

2 ADVANCES IN THE RESEARCH OF HPWH

Heat pump water heater is investigated to further improve coefficient of performance. Many aspects attracting researchers include the design of compressor, solar-assisted heat pump water heaters, alternative refrigerant technology for a compressor HPWH, frosting/defrosting of an air source heat pump water heater, tank of HPWH, and so on.

2.1 Compressor

Vapor compression heat pump is widely used in heat pump water heaters. As the compressor is the major component in a HPWH, advances in compressor efficiency have a significant affect on overall system efficiency. In the HPWH, condensing pressure will be very high when water temperature increases. If conventional compressor is used in the HPWH, on one hand, current of motor may increase and energy may be consumed more than expected. On another hand, the discharged temperature will be so high that working fluid and lubricant may decompose and insulation grade of motor may reduce, so special compressor which can adapt to high condensing temperature must be used in HPWH. As used in refrigeration system, co_2 has many prominent advantages compared with traditional working fluid;

so many researchers are attracted by the design of co_2 compressor.

Expander-compressor which was well engineered by P. Hey could move smoothly like a piston. This machine consisted of two pistons which were connected with a piston rod. Cylinders were divided into four parts which consisted of two expanded parts and two compressed parts. Although being very simple, the compressor was economy when running and it only need little lubricant [4]. The structure of compressor Fagerli designed was similar with R22 compressor, but its isentropic efficiency was lower than R22 compressor by 15% [5]. Suzai developed two-grade reciprocating compressor whose capability was 750W. Being use high strength steel ,the compressor could run naturally under pressure of 25 MPa[6]. On the base of R410A scroll compressor , Panasonic designed co_2 compressor whose delivery space was 71.23 cm^3. Refrigerating output of the machine could reach 2.15 － 5.10kw, and its volumetric efficiency could reach 70％－80％. Scroll compressor was also researched by Hasegawa, he found single volume efficiency of the compressor could reach 87％[7].Cooperating with UTC (United Technology Corporation). Compressor institution in xi'an jiaotong university designed rotary vane expander- compressor and piston expander-compressor , and co_2 compressor was also researched[8].

With the development of technology such as machining and control, compressor developed rapidly with high efficiency [9]. When new working fluid is being used, many researchers pay attention to the characteristic of lubricant. In Sun ang's experiment, titanium dioxide nanoparticles, which were capped with stearic acid, were prepared by sol-gel method. And titanium dioxide nanoparticles were then used as oil additives. The tribological performance of n-Tio_2 nanoparticles were evaluated on a four ball machine. The results showed these additives had an excellent load-carrying value, a antiwear and friction reducing abilities[10]. Sun analyzed the effects of different dispersing agents on dispersion behavior of nano-titania powders in aqueous solution. The experimental results indicated that when pH was 6-10, the satisfactory and stable dispersion Tio_2 in aqueous solution was obtained using NACL as dispersant which was 0.3% of Tio_2 in mass[11]. For the resolution of stability ultrafine powders lubricant, Hefeng analyzed the essential condition by which single particle and untrafine metal powders could disperse and suspend in liquid phases, the result pointed out just because of the surface coating and the space-resistive effect , and only the thickness of surface-coating was lager than 4.2 nm, the stable suspending of ultrafine powders in oil can be realized [12]. Gu Zhongming prepared the lubricating oil with $caco_3$ and rare earths nanoparticles. The results indicated that the lubricating oil had optimum properties of friction-reduction and wear resistance when the total additive content was 0.6%, and the optimal additive proportion of nanoparticles was $w(CaCo_3)$: w(RE) = 1:1 [13].

2.2 Solar-Assisted Heat Pump Water Heater

COP of ASHPWH will be very low when ambient temperature is low, while solar collector can work with a high efficiency. Combining heat pump and solar water heater system,, evaporator/collector can be operated at a high temperature, and COP would increase. This thought was first conceived by Jordan and Threlkeld in 1950s. Now many kinds of solar assisted heat pump water heating system have been designed.

Analytical and experimental studies were performed on a solar assisted heat pump water heating system by Hawlader. To ensure proper matching between the collector/evaporator load and compressor capacity, a variable speed compressor was used. Results showed that, the condensing temperature would increase when water temperature in the condenser tank increased with time, and the corresponding COP and collector efficiency values declined. Solar collector efficiency was found to vary between 40% and 75% for water temperatures in the condenser tank varying between 30°C and 50°C ,and average values of COP ranged from about 4 to 9 [14].Huang carried out a long-term reliability test of an integral-type solar-assisted heat pump water heater (ISAHP). During the past 5 yr the prototype had been

running continuously for more than 13,000 h with total running time more than 20,000 h. The measured energy consumption was 0.019 kWh/l of hot water at 57 ^{o}C that was much less than the backup electric energy consumption of the conventional solar water heater [15].Cheng Kung fabricated a prototype of direct-expansion solar-assisted heat-pump water heater. Its performance was investigated under the simulated solar radiation (0-1000 W/m^2). The results indicated that, the averaged values of system COP and heat output rate were about 4.18 and 1.04 kw[16].

2.3 The Tank and Condenser of Heat Pump Water Heater

The condenser of heat pump water heater is put in the tank in the form of submerged coil usually [17]. Temperature of the water in the tank increases with time. With the rising of water temperature, condensing pressure goes up too, so the structure of condenser is very important for the performance of heat pump water heater system. Improved structure of condenser and more efficient condenser coil are used to improve the performance of heat pump water heater system in domestic and aboard research [18-22].

At the same time, the stratification of water temperature in the tank, which is effected by the size of tank, the form of condenser coil and so on, is also attaining the attention of researchers. Chen, Fang C had done CFD simulation and experiment research on the temperature distribution of a HPWH tank, Result showed that when the condenser coil in the tank was in the shape of U, there was a temperature differential of 16°C (30°F) from top to bottom. However, when the coil was built in "L" shape, the water stratification disappeared [23]. On Minsung kim's research, finite volume method was applied to describe the heat exchangers, and lumped parameter models were used to analyze the compressor and the hot water reservoir. The result of simulation showed that, the smaller size of the water reservoir had larger transient performance degradation, and the larger size caused additional heat loss during the hot water storage period. Therefore, the reservoir size should be optimized in a design process to minimize both the performance degradation and the heat loss.[24].

Xiong zhen laid five heat-variable resistors to meter temperature in different heights of the tank when studied the performance of heat pump water heater system, the author presented that the control point of temperature should be in the 1/4 height of tank [25]. Chen zhen hao laid the temperature meter point in the middle of tank to obtain a exact water temperature [26]. JiJie ignored the difference of inner temperature of the hot water in tank, and assumed that temperature in the different water layers were same [27]. The temperature stratification phenomenon is existent in the tank objectively, while the temperature in the tank affected the system performance importantly, so further research should be performed on the phenomenon for improving the system performance.

2.4 Substitution of Hpwh Working Fluid

Research are performanced on innocuous mixture refrigerants and natural refrigerants in order to change the purpose from improving the capability to strengthening the protection of environment and from protecting the ozone to fulfilling the rule of ozone protect and preventing the globe warming.

Liebenberg evaluated heat pump water heater in terms of the viability of employing capacity control using non-azeotropic refrigerant mixtures (NARMs). By using (NARM) and changing the composition (x) of the circulating mixture, continuous capacity control could be offered. Computer simulations showed that, when operating between compositions of 100% R-22 and 70% R-22, the capacity-controlled heat pump showed a 29.6% improvement in energy conversion compared with a conventional R-22 heat pump water heater[28].According to the experiment , Mei VC also found that it was feasible that R-407C could be used to replace R-22 with improvement in water heating capacity without sacrificing the system energy efficiency[29].Cao feng had done some experiment on heat pump hot water system by R417a; experimental prototype was tested under different conditions by changing the temperature of the infall or changing the quantity of the water or changing the evaporating temperature. According to the result , the system pressure of R417a was reduced contrasted

with R22[30].Neksa did some research on co_2 hot-water heat pump system; he found a heating-COP of 4.3 was achieved for the prototype when heating tap water from 9°C to 60°C, at an evaporation temperature of 0°C. the primary energy consumption could be reduced with more than 75% compared with electrical or gas fired systems[31].Li xiaoyan had done some analyse on theoretical refrigeration cycle when using the mixture refrigerant R417a , a comparison test on using R407C to replace R22 was also performanced. The result indicated the heat output of mixture refrigerant R417a was lower than R22, however, COP of R417a system were superior than R22 system[32].

2.5 Frosting/Defrosting Of Air Source Heat Pump Water Heater

When indoor temperature is low , heat conduction would be affected due to frosting on the surface of the heat exchanger, as a result ,efficiency of ASHPWH will be very low. Many researchers have been done on the theory of frosting and the technique of defrosting.

According to the research ,Yangyao found when the relative humidity was increasing the rate of frosting was increased[33].According to the research Chen rudong found that the efficiency of rid would be increased due to the increase of frost at beginning, then it would be fixed. In the beginning, because of extend of the surface area of heat exchanger and the random of frosting , coarseness index of frosting surface would increase. At the same time frost resistance was increasing, so heat transfer would reduced at last[34].S.Z.Zhang had simulated the frost characteristic of Finned-tube evaporator by using R407C and built the distributing parameter model, he found the evaporating temperature would increase in the beginning of frost and then fixed , at last it would be reduced quickly. And he found the accumulated condition was related with the location of pipe and the route of the ventilation[35].Shi wenxing used different electromagnetic calves to research the performance of defrosting. Experimental results showed that the resistance of valve had a direct influence on the time and effect of defrosting .As well, when hot vapor bypass method was used to defrost, indoor thermal comfort could be increased greatly . If electronic expansion valve and bypass electromagnetic valve are used together, the effect of defrosting was increased and the time of defrosting was shortened[36].

3. CONCLUSION

1) Research should be further performanced on innocuous mixture refrigerants and natural refrigerants to improve COP of heat pump water heater .

2) Co_2 has many prominent advantages compared with traditional working fluid, so the design of co_2 compressor should be paid more attention in the future.

3) The temperature stratification phenomenon is existent in the tank of HPWH objectively, while the temperature in the tank affected the system performance importantly, so further research should be performed on the phenomenon for improving the system performance

4) Long-term reliability test of heat pump water heater should be carried out to improve the standard of design.

Compared with traditional water heating system, heat pump water heater has prominent advantages in energy-saving and environment-protecting .With the further research, coefficient of performance of HPWH will still increase in the future.

REFERENCES

[1] Sheldon, Theodore L. Tva's operational experiences with heat pump water heaters[C]. Proceedings of the 7th Heat Pump Technology Conference., 1984, 5p

[2] Ure, J. W.. Small air source heat pumps for hot water supply in commercial premises[J]. Heat Pumps for Build, 1984, p 218-247,

[3] Rousseau, P.G.; Greyvenstein, G.P.. Enhancing the impact of heat pump water heaters in the South African commercial sector[J]. Energy (Oxford)，2000，25（1），p 51-70

[4] P.Heyl, W.E.Kraus, H.Quack. Expander- compressor for a more efficient use as refrigerant of nature working fluids'98 June 2-5, 1998, Oslo, Norway: 195-203

[5] Fagerli .B On the feasibility of compressing co_2 as working fluid in hermetic reciprocating compressors: [Dr Ing Thesis]. Norway : Norwegian University of science and Technology,1997

[6] Suzai T, Sato A, Tadano M, et al. Development of a carbon dioxide compressor for refrigerators and air conditioners[C] . Conference of the Japan Society of Refrigerating and Air Conditioning Engineers, Tokyo, 1999

[7] Hasegawa H. Ikona M, Nishawaki F, et al. Experiment and theoretical study of hermetic co_2 scroll compressor[C]. The Fourth IIR-Gustav Lorentzen Conference on Natural Working Fluids, West Lafayette .2000

[8] Guo pei .Review on the development of carbon dioxide heat pump water heater system and its compressor[J] . Science and Technology of Household Electric Appliance , 2005（9）p42-44

[9] Li lian-sheng . Development of refrigerating and air-conditioning compressor[J]. Process of refrigerating and air-conditioning technology , 2005,p 31-37

[10] Sun ang . Characterization and research on the tribological performance in lubricating oil of nano-Tio_2[J] . Joural of dalian maritime university .2003, 29(3)

[11] Sun xiu-guo ,Effects of dispersing agents on spersion behavior of nano-titania powers[J] . Semiconductor technology, 2006,31 (5)

[12] Hefeng ,Zhang zhen-yi . Stability research of ultrafine powders lubricant [J] , Journal of university of science and technology Beijing, 2000, 22(3):253-255

[13] Gu zhong-ming .Tribology properties of lubricating oils containing Nanoparticles of $caco_3$ and rare earths [J] .Lubrication engineering , 2005, 172 (6)

[14] Hawlader, M.N.A.; Chou, S.K.; Ullah, M.Z.. The performance of a solar assisted heat pump water heating system[J] . Applied Thermal Engineering，2001，21（10），p 1049-1065

[15] Huang, B.J.; Lee, C.P.. Long-term performance of solar-assisted heat pump water heater. Renew[J]. Energy,2004,29(4), p 633-639

[16] Kim, Minsung; Kim, Min Soo; Chung, Jae Dong. Transient thermal behavior of a water system driven by a heat pump[J] . International Journal of Refrigeration, 2004, 27 (4), p 415-421

[17] Tang wen-tao . Reseacch on an air-source heat pump water heater with a new ODS free alternative working fluids[D] . Beijing institute of civil engineering and architecture , 2006.3

[18] Shen wen-sheng. The optimal fin space of vertical rectangular straight fins in forced convective heat transfer[J] . Fluid machinery, 1999,27(7)

[19] Xin rong-chang . An experimental investigation on heat transfer and pressure drop characteristics of triangular wavy fin-and-tube heat exchanger surfaces[J] . Journal of xi'an jiaotong university , 1994 ,28 (2)

[20] Kang hai-jun . Experimental study on heat transfer and pressure drop for plane fin-and-tube heat exchanger[J] . Journal of xi'an jiaotong university , 1994 28 (1)

[21] Wang sui-lin . Affection on fin-and-tube Heat Exchanger's Properties by non azeotropic mixtures[J] . Fluid machinery , 1996 , 24 (5)

[22] Ge run-ting . Foundation of Dynamic Parameter Model and Theoritical Calculation of Evaporator[J] . Refrigeration journal , 1995.No.1

[23] Chen, Fang C. CFD solution and experimental testing of buoyancy-driven convection caused by condensers immersed in a water tank of HPWH[C] 2003 ASME International Mechanical Engineering Congress

[24] Minsung kim .Transient thermal behavior of a water system driven by a heat pump[J] . International Journal of Refrigeration June ,2004 , p 415-421

[25] Xiong zhen-qin . Experimental study on a small size air-source heat pump water heater[J] . Process of refrigerating and air-conditioning technology , 2005,p182-186

[26] Chen zheng-hao . Optimization of air-source heat pump water heater system based on seasonal performance experiment[J] . energy technology , 2005 , 26 (3) , p117-119

[27] Ji jie . Performance simulation and experiment of an air conditioner incorporated with a water heater in cooling and hot water supply[J] . HA&VC , 2003,33(2), p19-23

[28] Liebenberg, Leon; Meyer, Josua P.. Viability of capacity control of high temperature heat pump water heaters operating non-azeotropic mixtures[J]. American Society of Mechanical Engineers (Paper), 1997, 97-AA-28

[29] Mei, V.C.; Domitrovic, R.E.; Brewer, W.H.; Chen, F.C.; Doctor, T.R.. Experimental study of an R-407C heat pump water heater[J]. ASHRAE Transactions, 2001，v 107 PART. 1，p 224-229

[30] Cao feng . Experimental study on R417a used in Heat Pump Heating Water System[J] . Fluid machinery . 2005,33，p117-120

[31] Neksa, Petter; Rekstad, Havard; Zakeri, G. Reza; Schiefloe, Per Arne. CO2-heat pump water heater: characteristics, system design and experimental results[J]. International Journal of Refrigeration，1998，21（3），p 172-179

[32] li xiao-yan . Experimental Study on Replacement of R22 with R417a in Heat Pump Heating Water System[J] . Refrigeration Journal , 2003，4，p1-3

[33] Yao, Yang; Jiang, Yiqiang; Ma, Zuiliang; Deng, Shiming. Study on performance of air source heat pump water heater/chiller unit under frosting. Energy Environ[C]. Proc. Internat. Conf. Energy Environ.,2003, V2, p 1563-1567

[34] Chen ru-dong . Affection on Heat Exchanger's Properties by Frosting[J] . Building energy & environment , 1999a（3）16－19

[35] S.Z.Zhang et al. Study on frosting characteristics of an evaporator using R407c as refrigerant[C]. International Symposium of Air Conditioning in High Rise Buildings 2000 shanghai, 2000.10 ;269-273

[36] Shi wen-xing . Exeprimental Research on Hot Vapor Bypass Defrosting Method[J] . Refrigeration journal , 2000（2）：29－35