International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

2012

Heat Pump Efficiency Improvement by Discharge Superheated Control

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ABSTRACT

This research presents how to improve the heat pump efficiency by using Discharge Superheat Control (DSH). Normal heat pump uses Suction Superheat Control (SSH) about 5 K. At this condition, it is an optimum condition for cooling COP but it is not the highest cooling capacity. To improve Heat Pump efficiency, it needs to get maximum heat from Evaporator and internal heat of Compressor to discharge at Condensing. This condition needs to be controlled at SSH ~ 0 K. Unfortunately normal heat pump can not be controlled at this condition because of limitation of expansion valve controlling and operating limit of some compressor. New control method under this condition, is called Discharge Superheat Control (DSH). It uses discharge temperature for controlling refrigerant flow to get the maximum heat at Evaporator and Compressor. From the experiment with Brine to Water(BTW) and Air to Water Heat Pump (ATW), DSH control will lead to highest HCOP up to 25 % improved, comparing to the original control method.

1. INTRODUCTION

The demand for energy efficiency of heat pump has been increased since the environmental protection becomes more severe. Inverter solution is popular method to improve heat pump efficiency but user must to pay much money for high price components, such as BLDC motor for water pump and compressor, Inverter driver for speed control. In this research shows cheaper and more effective way to improve efficiency of heat pump by only changing superheat control method from at suction side to at discharge side.

Normal BTW and ATW Heat Pump use Thermostatic Expansion Valve (TXV) for suction side superheat control at ~5 K. This value is fixed at all running condition of heat pump. Then refrigerant flow cannot adjust to optimum point for highest efficiency at each condition. The best efficiency of heat pump should be controlled superheat at Evaporator around 0 K. From both reasons, superheat control should be changed to control at discharge side and by Electronic Expansion Valve (EEV).

Control of superheat at 0 K by new DSH control method can not use with low pressure shell type hermetic compressor because the compressor will be damaged from bad lubrication which causes from high solubility of wet refrigerant into the compressor oil at the oil sump. But it works very well with high pressure shell type hermetic compressor because wet refrigerant will go direct into compression chamber instead of oil sump and the refrigerant is heated up immediately by compression process. So, high pressure shell type hermetic compressor is suitable to use with new DSH control.

2. SYSTEM CONFIGURATION

The schematic diagram of normal heat pump is shown in Figure 1. The system uses TXV for controlling refrigerant flow into evaporator to have target superheat by using P_s and T_s.
New DSH control method for Heat Pump is shown in Figure 2. It uses EEV to controls DSH by P_d and T_d for adjusting refrigeration flow.

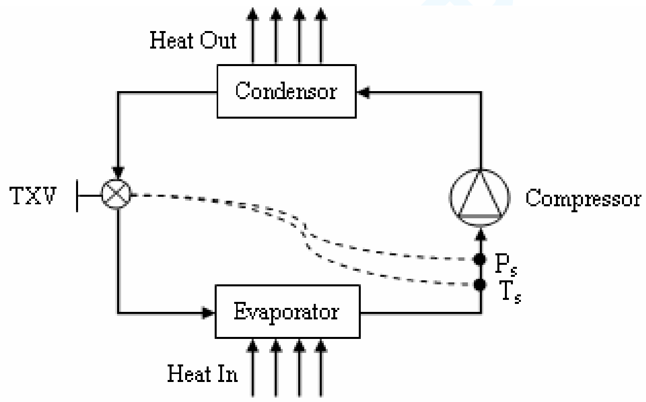

Figure 1 : The schematic diagram of Normal Heat Pump with SSH control.

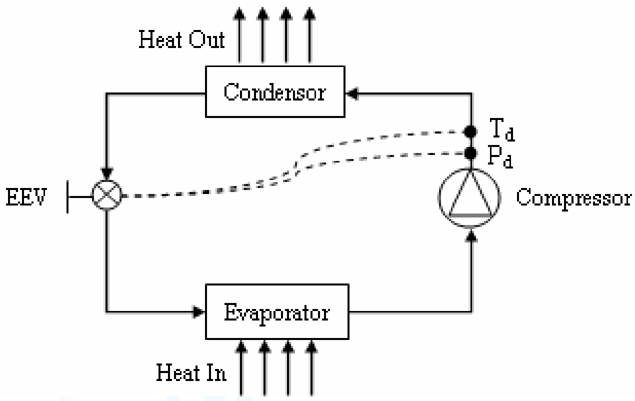

Figure 2 : The schematic diagram of Heat Pump with DSH control.

DSH as shown in P-h diagram of Figure 3 can be calculated from T_{sat} of P_d and T_d as Equation (2).

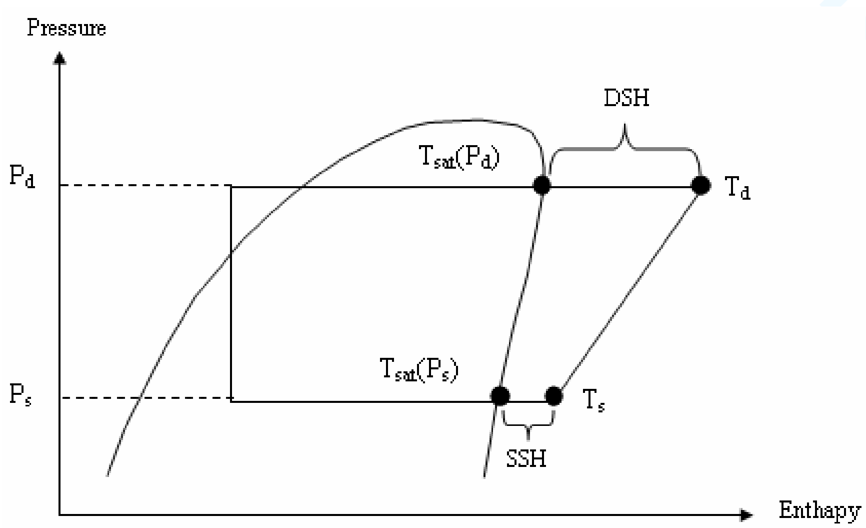

Figure 3 : P-h diagram for SSH and DSH control

Suction Superheated is calculated by T_s and P_s as Equation (1)

$$SSH = T_s - T_{sat}(at\ P_s) \quad (1)$$

Discharge Superheated is calculated by T_d and P_d as Equation (2)

$$DSH = T_d - T_{sat}\ (at\ P_d) \quad (2)$$

Figure 4 shows the effect of wet refrigerant in Low pressure shell type hermetic compressor and High pressure shell type hermetic compressor. Incase SSH<0 K, Low pressure shell type hermetic compressor will have problem of bad lubrication because refrigerant will condense in the compressor shell and condensed refrigerant will dissolve into the compressor oil. Then it effects to low viscosity for compressor's part lubrication but High pressure shell type hermetic compressor can work with some wet refrigerant because wet refrigerant will evaporate to be gas immediately by compression process after flow into the compression chamber of compressor. Therefore discharge refrigerant can keep superheat to condensing temperature. It will not condense in the compressor shell and not reduce oil viscosity.

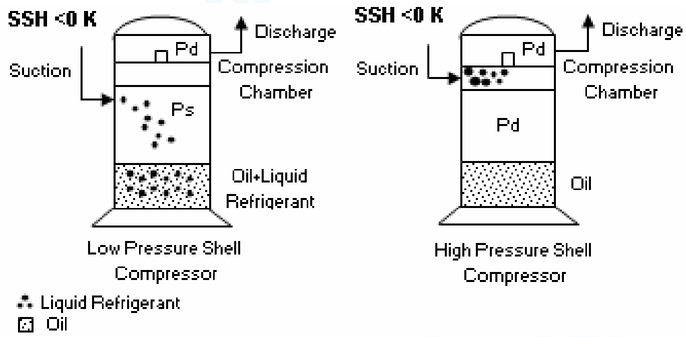

Figure 4 : Comparison of Low pressure shell type hermetic compressor and High pressure shell type hermetic compressor with wet refrigerant condition at suction line.

3. EXPERIMENTAL UNIT AND TESTING CONDITION

3.1 Brine to Water Heat Pump

Experimental unit for BTW Heat pump is shown in Figure 5. The evaporator and condenser are plate heat exchanger. The compressor is High Pressure shell type Hermetic scroll compressor from Siam Compressor Industry (SCI). The expansion device is electronic expansion valve. The refrigerant is R-410A. Brine water is 50 % of propylene glycol. Ambient temperature is not controlled. It was about 30 ^{o}C. All refrigerant parts are insulated except compressor's shell. The test condition is shown in Table 1.

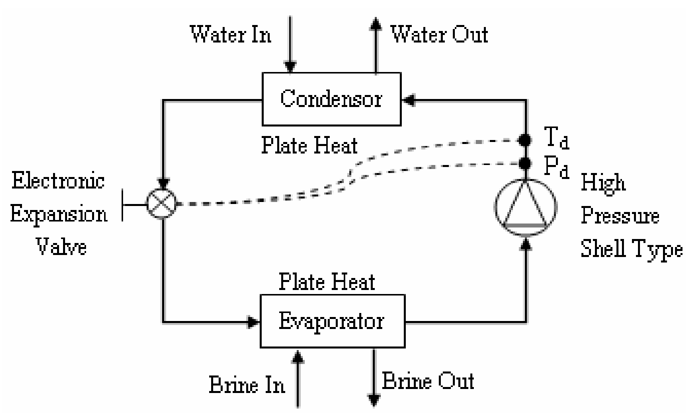

Figure 5 : Experimental Unit BTW Heat Pump

Condition	Brine Temp(°C)		Water Temp(°C)		Condition	Brine Temp(°C)		Water Temp(°C)	
	Inlet	Outlet	Inlet	Outlet		Inlet	Outlet	Inlet	Outlet
1	-15	-18	30	35	9	0	-3	30	35
2			40	45	10			40	45
3			50	55	11			50	55
4			55	60	12			55	60
5	-10	-7	30	35	13	20	17	30	35
6			40	45	14			40	45
7			50	55	15			50	55
8			55	60	16			55	60

Table 1 : Testing Condition of Brine to Water Heat Pump

3.2 Air to Water Heat Pump

Experimental unit for ATW Heat pump is shown in Figure 6. The condenser is plate heat exchanger. The evaporator is air heat exchanger. The compressor is High Pressure shell type Hermetic scroll compressor from Siam Compressor Industry (SCI). The expansion device is electronic expansion valve. The refrigerant was R-410A. All refrigerant parts are insulated except compressor's shell. The test condition is shown in Table 2.

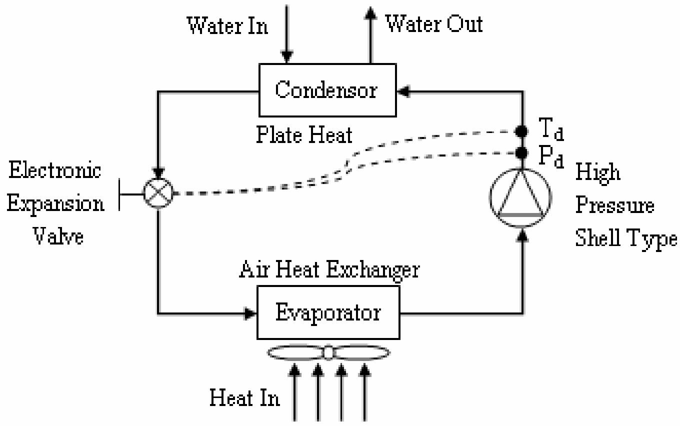

Figure 6 : Experimental Unit ATW Heat Pump

Condition	Air Temp(°C)		Water Temp(°C)		Condition	Air Temp(°C)		Water Temp(°C)	
	DB	WB	Inlet	Outlet		DB	WB	Inlet	Outlet
1	-15	N/A	30	35	7	2	1	30	35
2			35	40	8			35	40
3			40	45	9			40	45
4	-7	N/A	30	35	10	7	6	30	35
5			35	40	11			35	40
6			40	45	12			40	45

Table 2 : Testing Condition of Air to Water Heat Pump

4. TESTING RESULTS

4.1 Brine to Water Heat Pump

Figure 7-10 shows the efficiency of BTW Heat Pump at various points of brine temperatures at fixed hot water temperature of 35 °C. As a result, at every brine temperature conditions show the same trend that both cooling capacity and power input are increased when increases refrigerant flow into evaporator to have SSH lower than 5 K. The increase rate of cooling capacity is more than power-input's increasing rate. Consequently HCOP is increase at SSH lower than 5 K. The HCOP starts to reduce after SSH<0 K. So, HCOP of heat pump will get highest efficiency at SSH around 0 K at all brine temperature conditions and the increasing of HCOP up to 25 %

At 0 K of SSH, it is not possible to control expansion device by using suction side condition. Then it needs to change control to be discharge side superheat control or DSH control which still has enough superheat value to be controlled. And, the highest efficiency of heat pump will be at DSH from 15 K to 30 K

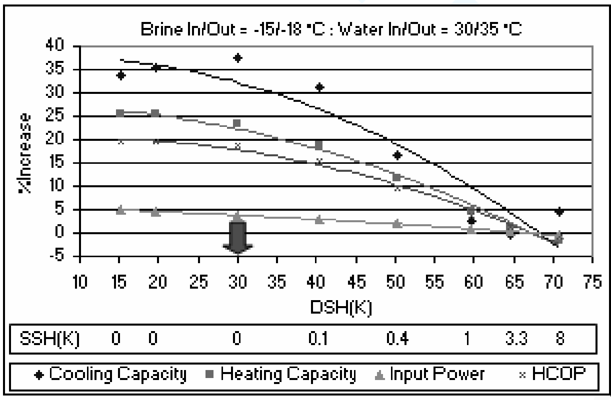

Figure 7 : Testing results of BTW Heat Pump when Brine temperature In/Out = -15/-18 ^{o}C (Note : 0% at SSH=5 K)

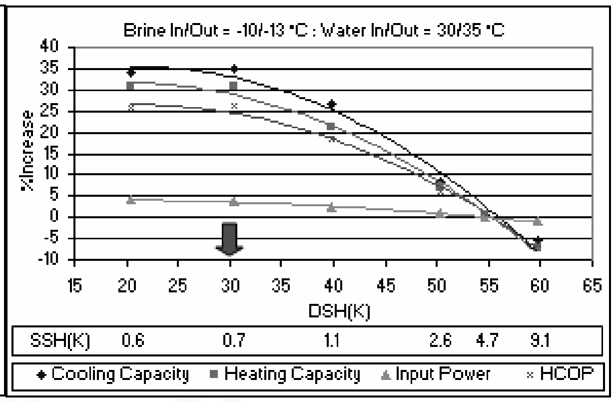

Figure 8 : Testing results of BTW Heat Pump when Brine temperature In/Out = -10/-13 ^{o}C (Note : 0% at SSH=5 K)

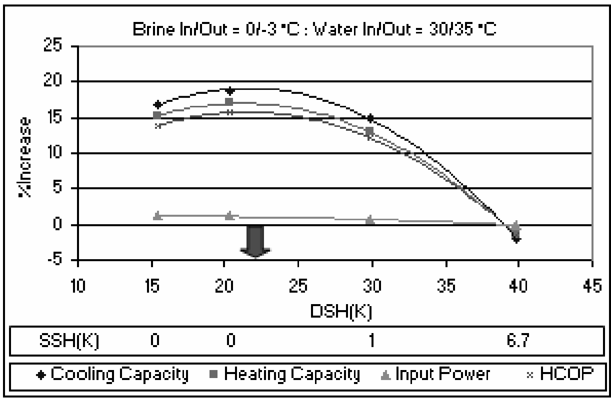

Figure 9 : Testing results of BTW Heat Pump when Brine temperature In/Out = 0/-3 ^{o}C (Note : 0% at SSH=5 K)

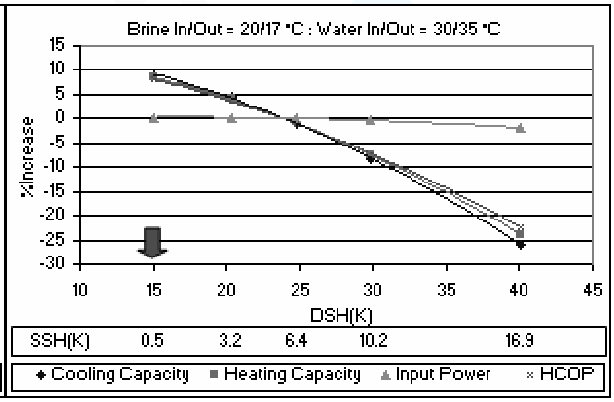

Figure 10 : Testing results of BTW Heat Pump when Brine temperature In/Out = 20/17 ^{o}C (Note : 0% at SSH=5 K)

Figure 11-13 shows the efficiency of BTW Heat Pump at various points of hot water temperatures at fixed Brine temperature of 0 °C. As a result, all hot water temperature condition show the same results as varying of Brine temperature that the highest efficiency has SSH around 0 K at all hot water temperature conditions.

The improvement of efficiency up to15 % when vary hot water temperature. And the highest efficiency of heat pump will be at DSH from 15 K to 30 K.

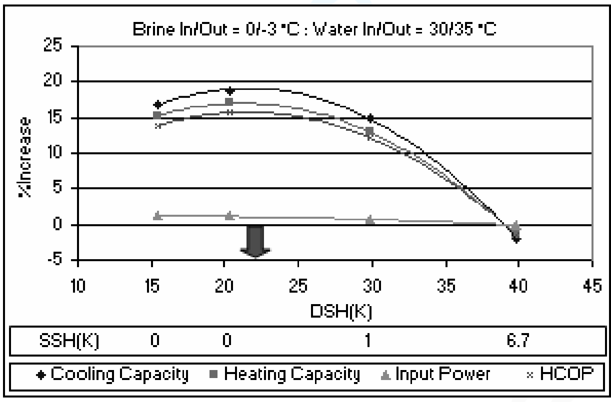

Figure 11 : Testing results of BTW Heat Pump when Water temperature In/Out = 30/35 ^{o}C (Note : 0% at SSH=5 K)

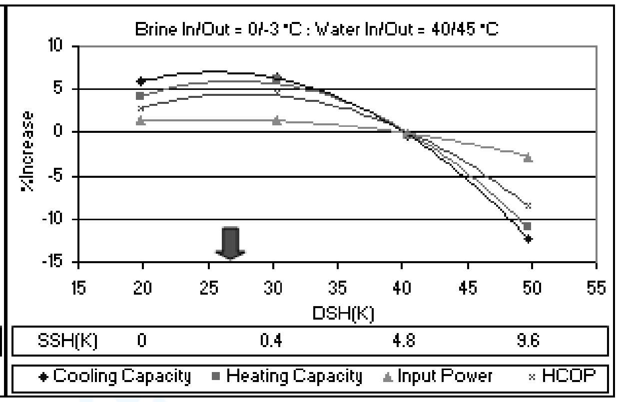

Figure 12 : Testing results of BTW Heat Pump when Water temperature In/Out = 40/45 ^{o}C (Note : 0% at SSH=5 K)

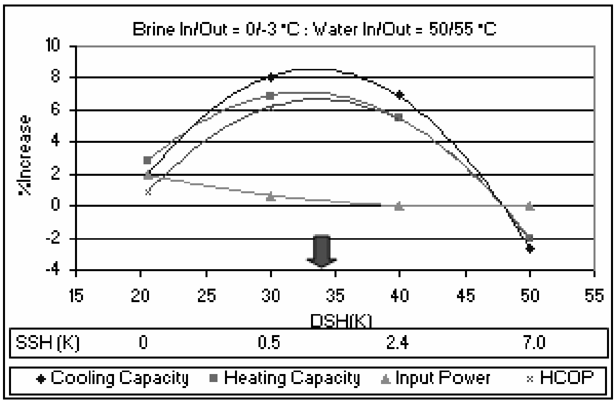

Figure 13 : Testing results of BTW Heat Pump when Water temperature In/Out = 50/55 ^{o}C (Note : 0% at SSH=5 K)

From all results in Figure 7 & 13, the optimum DSH value has linear relation with Compression ratio value (Pd/Ps) as shown in Figure 14. To apply DSH control, the relation can be programmed into the controller for Electronic expansion valve control.

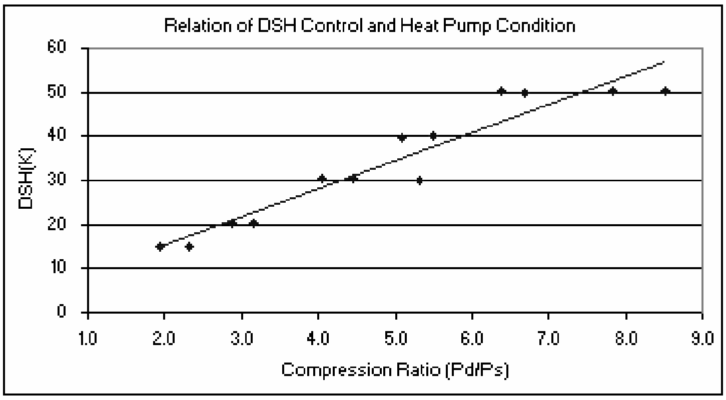

Figure 14 : Relation of DSH Control value and Compression Ratio value for BTW HP.

4.2 Air to Water Heat Pump

Figure 15-18 shows the efficiency of ATW Heat Pump by varying the ambient temperature at fixed hot water temperature of 35 °C. As a result, all ambient temperature condition show the same trend that the best efficiency of heat pump is at SSH around 1 K. The HCOP start to reduce after SSH < 1 K.
At 1 K of SSH, it is not possible to control expansion device by using suction side condition. Then it needs to change control to be discharge side superheat control or DSH control which still has enough superheat value to be controlled. And, the highest efficiency of heat pump will be at DSH from 30 K to 45 K and the increasing of HCOP up to 12 %.

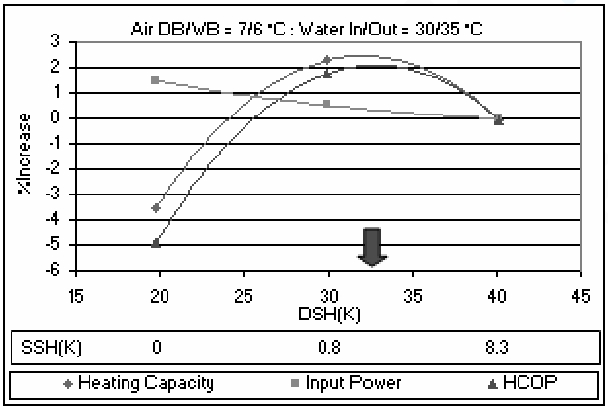

Figure 15 : Testing results of ATW Heat Pump when ambient temperature DB/WB = 7/6 ^{o}C (Note : 0% at SSH=8 K)

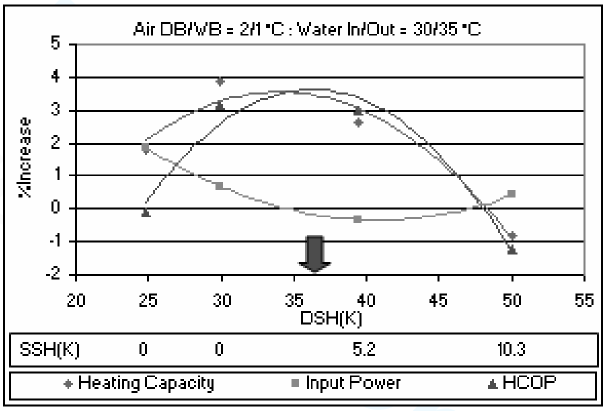

Figure 16 : Testing results of ATW Heat Pump when ambient temperature DB/WB = 2/1 ^{o}C (Note : 0% at SSH=8 K)

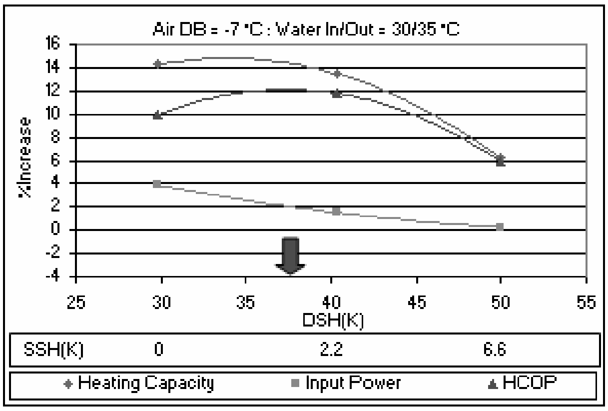

Figure 17 : Testing results of ATW Heat Pump when ambient temperature DB = -7 ^{o}C (Note : 0% at SSH=8 K)

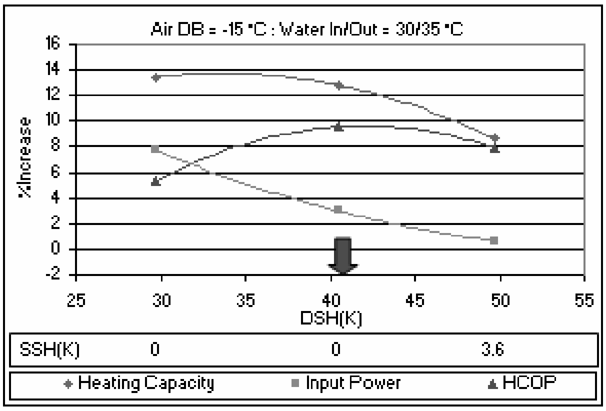

Figure 18 : Testing results of ATW Heat Pump when ambient temperature DB = -15 ^{o}C (Note : 0% at SSH=8 K)

Figure 19-21 shows the efficiency of ATW Heat Pump at various point of hot water temperatures at fixed ambient temperature of DB=2 °C/WB=1 ^{o}C. As a result, all hot water temperature condition show the same results that the highest efficiency has SSH around 1 K at all hot water temperature conditions. The improvement of efficiency up to 7 % when vary hot water temperature. And the highest efficiency of heat pump will be at DSH from 30 K to 40 K. For ATW Heat Pump the efficiency improvement from DSH control is not as high as BTW Heat pump because ATW HP has longer piping between evaporator and compressor than BTW HP. So there is pressure drop effect at suction side when the expansion valve give more refrigerant flow to evaporator.

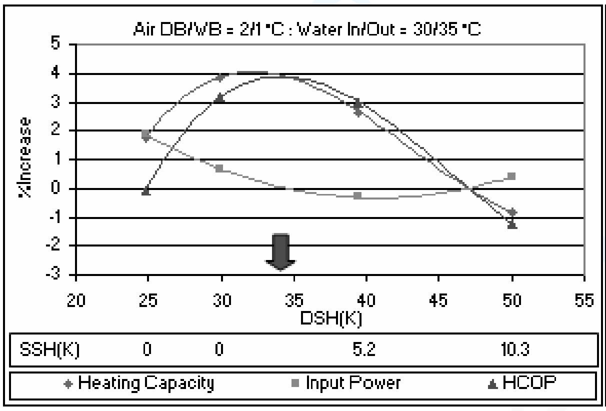

Figure 19 : Testing results of ATW Heat Pump when water temperature In/Out = 30/35 °C (Note : 0% at SSH=8 K)

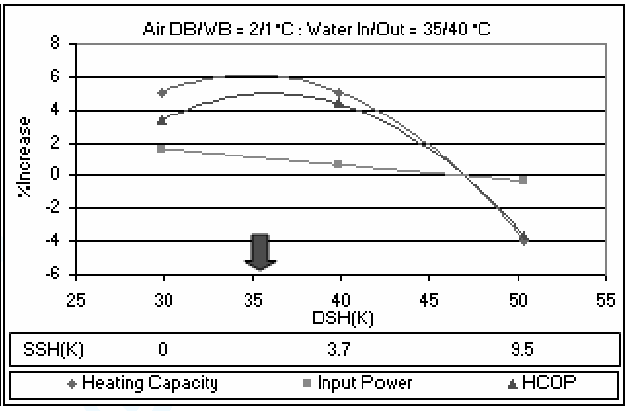

Figure 20 : Testing results of ATW Heat Pump when water temperature In/Out = 35/40 °C (Note : 0% at SSH=8 K)

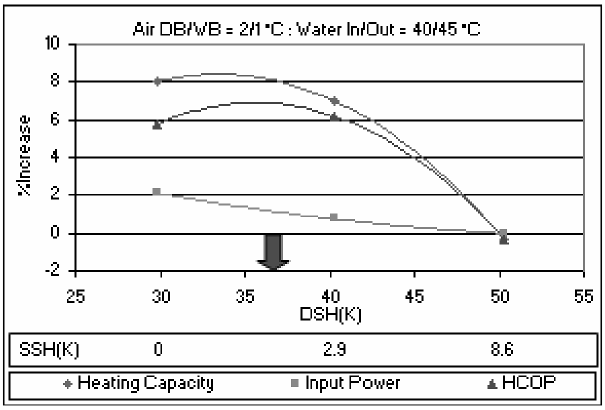

Figure 21 : Testing results of ATW Heat Pump when water temperature In/Out = 40/45 °C (Note : 0% at SSH=8 K)

From all results in Figure 15-21, the optimum DSH value has linear relation with Compression ratio value (Pd/Ps) as shown in Figure 22. To apply DSH control, the relation can be programmed into the controller for Electronic expansion valve control.

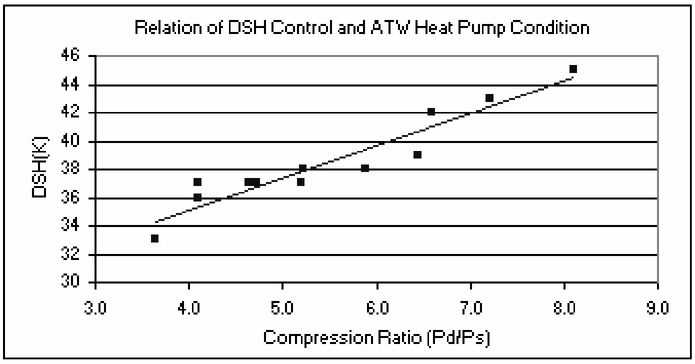

Figure 22 : Relation of DSH Control value and Compression Ratio value for ATW HP.

5. CONCLUSION

In this paper shows cheaper and more effective way to improve heat pump efficiency by DSH control.

1. The best efficiency of heat pump show at SSH ~0 K for BTW Heat Pump and SSH ~1 K for ATW Heat Pump. So it cannot be controlled by original method.
2. DSH control can be applied to both BTW and ATW HP to get highest efficiency.
3. The optimum DSH value has linear relation with Compression ratio value.
4. DSH control must be used with Electronic Expansion Valve.
5. DSH control can improve efficiency of BTW Heat Pump up to 25 % and ATW Heat Pump up to 12 %.
6. DSH control is suitable to use with high pressure shell type hermetic compressor.

NOMENCLATURE

SSH	Suction Superheated
DSH	Discharge Superheated
HCOP	Heating Coefficient of Performance
BTW	Brine to Water
ATW	Air to Water
HP	Heat Pump
EEV	Electronic Expansion Valve
TXV	Thermostatic Expansion Valve
P	Pressure
T	Temperature
h	Enthalpy

Subscripts

d	Discharge
s	Suction
sat	Saturated

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