CHAPTER 5

SYSTEM SIMULATION OF THE ADSORPTION COOLING SYSTEM WITH SONIC VIBRATION AT EVAPORATOR AND ADSORBER

In this chapter, the results from simulations of the adsorption cooling system, and their verification, are interpreted and discussed. Both its evaporator and adsorber were equipped with the sonic wave generator.

5.1 Operating conditions and constants for simulation

The adsorption cooling system was similar to the experimental unit described in Chapters 3 and 4. Tables 5.1 to 5.4 give summaries of the conditions for the calculation of when the evaporator is vibrated by the sonic wave. Tables 5.1 and 5.2 give the operating conditions at the adsorber, evaporator, condenser and sonic wave generator, and the constants for calculation, if the wave generator was equipped to the evaporator. However, Tables 5.3 and 5.4 give those operating conditions, if the wave generator is equipped to the adsorber.

Table 5.1 The operating conditions of the adsorber, evaporator, condenser and sonic-wave generator (sonic wave generator at the evaporator).

No.	Parameter	Symbol	Condition
1	Mass of activated carbon	m_{ac}	0.50 kg
2	Volume of methanol	V_{met}	900 cm^3
3	Mass flow rate of hot water and cooling water at the adsorber	$\dot{m}_{hw,ads} / \dot{m}_{cw,ads}$	0.08 and 0.035 kg/s
4	Mass flow rate of cooling water at the condenser	$\dot{m}_{cw,cond}$	0.06 kg/s
5	Mass flow rate of cooling water at the evaporator	$\dot{m}_{cw,evap}$	0.0018 kg/s

Table 5.1 The operating conditions of the adsorber, evaporator, condenser and sonic-wave generator (sonic wave generator at the evaporator) (continuous).

No.	Parameter	Symbol	Condition
6	Inlet temperature of hot water and cold water at the adsorber	$T_{hw,ads}$ / $T_{cw,ads}$	95°C and 28°C
7	Maximum temperature of activated carbon	T_{ac}	70, 80, 90°C
8	Inlet temperature of cooling water at the condenser	$T_{cw,cond}$	5, 10, 15°C
9	Inlet temperature of water at the evaporator	$T_{wi,evap}$	28°C
10	Sonic wave generator	Q_{sonic}	8, 10, 14 kHz (6.41, 27.94, 65.85 W)
11	Working pairs	AC/Met.	0.50 kg/900 cm^3

5.2 Flow chart of simulation program for adsorption cooling system

The flow chart structure showing algorithm of the simulation program (Figure 5.1). The program was written in the MS Excel 2007 worksheet, an efficient tool for scientific and engineering computation. The adsorption system model comprised of an adsorber, an evaporator and a condenser lumped sub-models. This type of model has already been proved for its accuracy in Sangtianchai work (2009) as compared to a 1-D model. The equations used for the calculations are given in Chapter 2, from equation 2.1 to 2.24, they are also indicated in the flow chart in Figure 5.1.

The program computed each component step by step, including isosteric heating-heating/condensation-isosteric cooling-cooling/adsorption processes, based on the inputs given in Tables 5.1 to 5.4. These sub-models were linked to each other by temperatures and mass flow rate of the working fluid, also the transported mass of methanol.

The program predicts the 1-minute time step temperatures of the adsorbent bed, the methanol, evaporator, condenser, outlet working fluid, as well as the mass fraction of the methanol in the adsorber. Therefore, the system performance could

easily be predicted. Finally, three performance indicators; COP, SCP and VCP were calculated.

The operating conditions used for the four processes in each cycle are shown in Figure 5.2 adjusting initial adsorbent bed temperature, wave frequency and the initial maximum adsorbed mass of methanol.

Table 5.2 Constants for calculation (sonic wave generator at the evaporator).

No.	Parameter	Symbol	valve
1	Density of methanol	ρ_{met}	800 kg/m^3
2	Specific heats of methanol	$c_{p,met}$	2.53 kJ/kg K
3	Specific heats of activated carbon	$c_{p,ac}$	0.7 kJ/kg K
4	Latent heat of methanol	L_{met}	1,168.22 kJ/kg
5	Mass of activated carbon	m_{ac}	0.5 kg
6	Volume of the adsorber	V_{ads}	1,521 cm^3
7	Overall heat transfer coefficient at the evaporator	U_{evap}	0.049 kW/m^{2}K
8	Area of the evaporator	A_{evap}	0.047 m^2
9	Overall heat transfer coefficient at the condenser	U_{cond}	0.049 kW/m^{2}K
10	Area of the condenser	A_{cond}	0.047 m^2
11	Overall heat transfer coefficient at the adsorber : hot water	U_{hw_ads}	0.026 kW/m^{2}K
12	Overall heat transfer coefficient at the adsorber : cooling water	U_{cw_ads}	0.048 kW/m^{2}K
13	Area of the adsorber	A_{ads}	0.2 m^2

Table 5.3 The operating conditions of the adsorber, evaporator, condenser and sonic wave generator (sonic wave generator at the adsorber).

No.	Parameter	Symbol	Condition
1	Mass of activated carbon	m_{ac}	0.50 kg
2	Volume of methanol	V_{met}	900 cm^3
3	Mass flow rate of hot water and cooling water at the adsorber	$\dot{m}_{hw,ads} / \dot{m}_{cw,ads}$	0.08 and 0.035 kg/s
4	Mass flow rate of cooling water at the condenser	$\dot{m}_{cw,cond}$	0.06 kg/s
5	Mass flow rate of cooling water at the evaporator	$\dot{m}_{cw,evap}$	0.0018 kg/s
6	Inlet temperature of hot water and cold water at the adsorber	$T_{hw,ads} / T_{cw,ads}$	95°C and 26°C
7	Maximum temperature of activated carbon	T_{ac}	80, 90°C
8	Inlet temperature of cooling water at the condenser	$T_{cw,cond}$	26°C
9	Inlet temperature of water at the evaporator	$T_{wi,evap}$	10, 15, 20°C
10	Sonic wave generator	Q_{sonic}	8, 10, 14 kHz (6.41, 27.94, 65.85 W)
11	Working pair	AC/Met.	0.50 kg/900 cm^3

Table 5.4 Constants for calculation (sonic wave generator at the adsorber).

No.	Parameter	Symbol	valve
1	Density of methanol	ρ_{met}	800 kg/m^3
2	Specific heats of methanol	$c_{p,met}$	2.53 kJ/kg K
3	Specific heats of activated carbon	$c_{p,ac}$	0.7 kJ/kg K
4	Latent heat of methanol	L_{met}	1,168.22 kJ/kg
5	Mass of activated carbon	m_{ac}	0.5 kg
6	Volume of the adsorber	V_{ads}	1,521 cm^3
7	Overall heat transfer coefficient at the evaporator	U_{evap}	0.049 kW/m^{2}K
8	Area of the evaporator	A_{evap}	0.047 m^2
9	Overall heat transfer coefficient at the condenser	U_{cond}	0.049 kW/m^{2}K
10	Area of the condenser	A_{cond}	0.047 m^2
11	Overall heat transfer coefficient at the adsorber : hot water	U_{hw_ads}	0.026 kW/m^{2}K
12	Overall heat transfer coefficient at the adsorber : cooling water	U_{cw_ads}	0.048 kW/m^{2}K
13	Area of the adsorber	A_{ads}	0.2 m^2

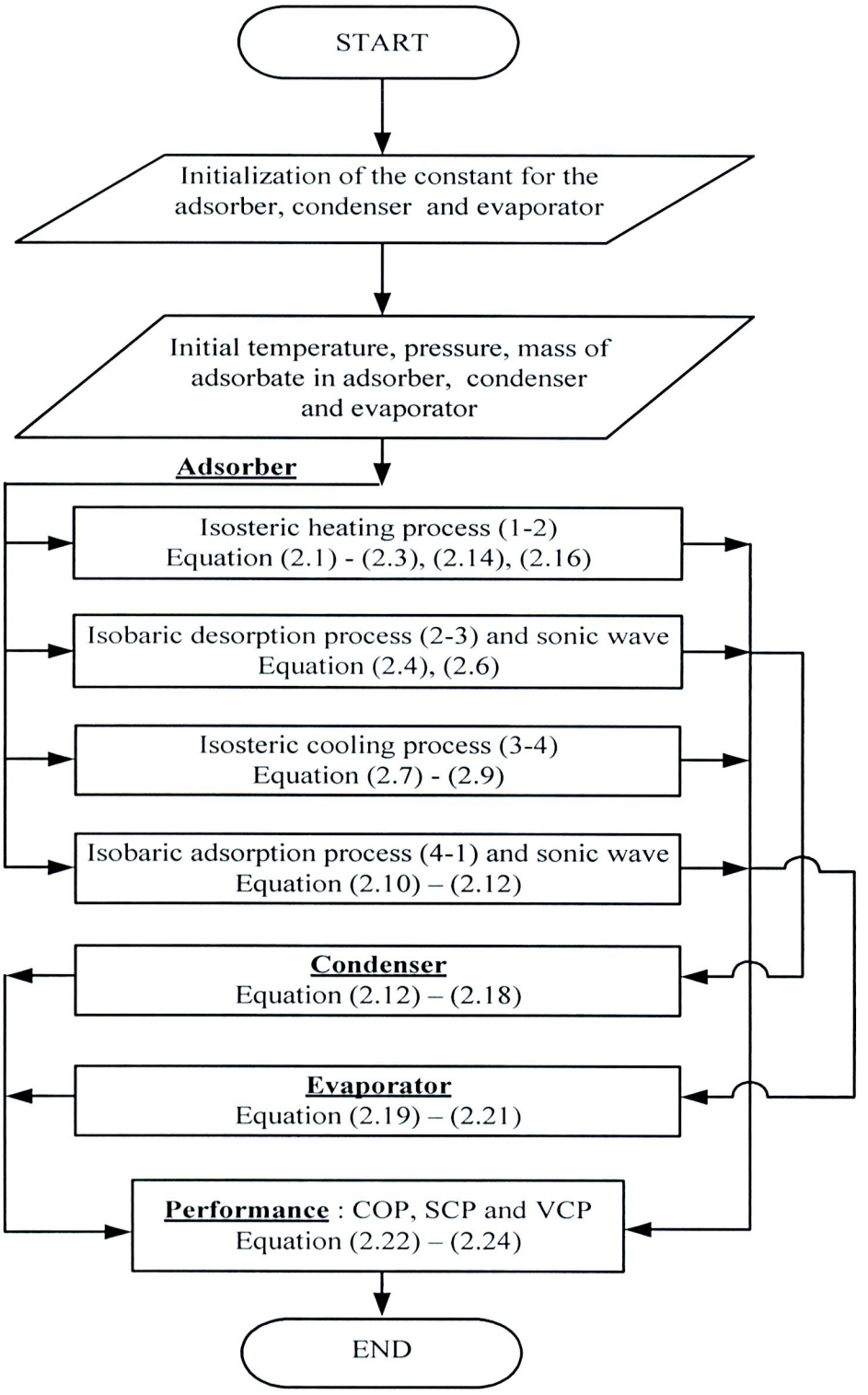

Figure 5.1. Flow chart for input and output data of the computer program.

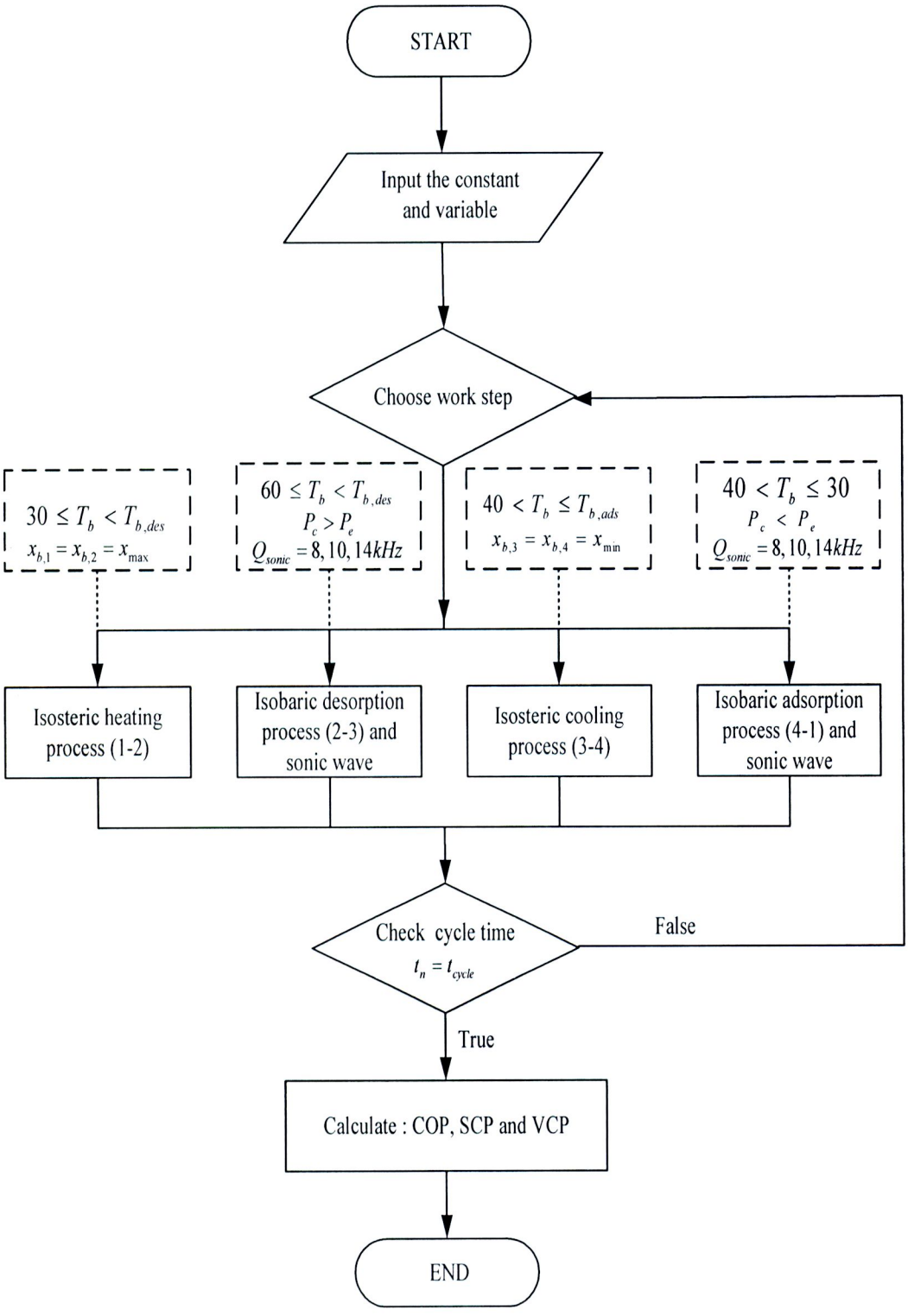

Figure 5.2. Flow chart of the simulation program for the adsorption cooling cycle.

5.3 Verification of the simulation results

The calculated results were compared with the experimental ones to verify the accuracy of the simulation program. Temperature profiles for the whole cycle of the adsorbent bed (T_b), evaporator (T_{ev}), condenser (T_{cd}) and the outlet cooling water from the adsorber ($T_{we,ads}$), as compared between the calculated and experimental are depicted in Figures 5.3 and 5.4.

The predictions were accomplished in both (sonic wave location) cases, all computed temperature profiles sufficiently followed the experimental results. The errors of COP, SCP and VCP predictions from Figure 5.3, in case of applying sonic wave at the evaporator were 11.07%, 17.05 % and 17.05 %, respectively. However, those errors obtained from the case applying sonic wave at the adsorber as showed profiles in Figure 5.4 of 6.03%, 3.54 % and 3.54 %, respectively.

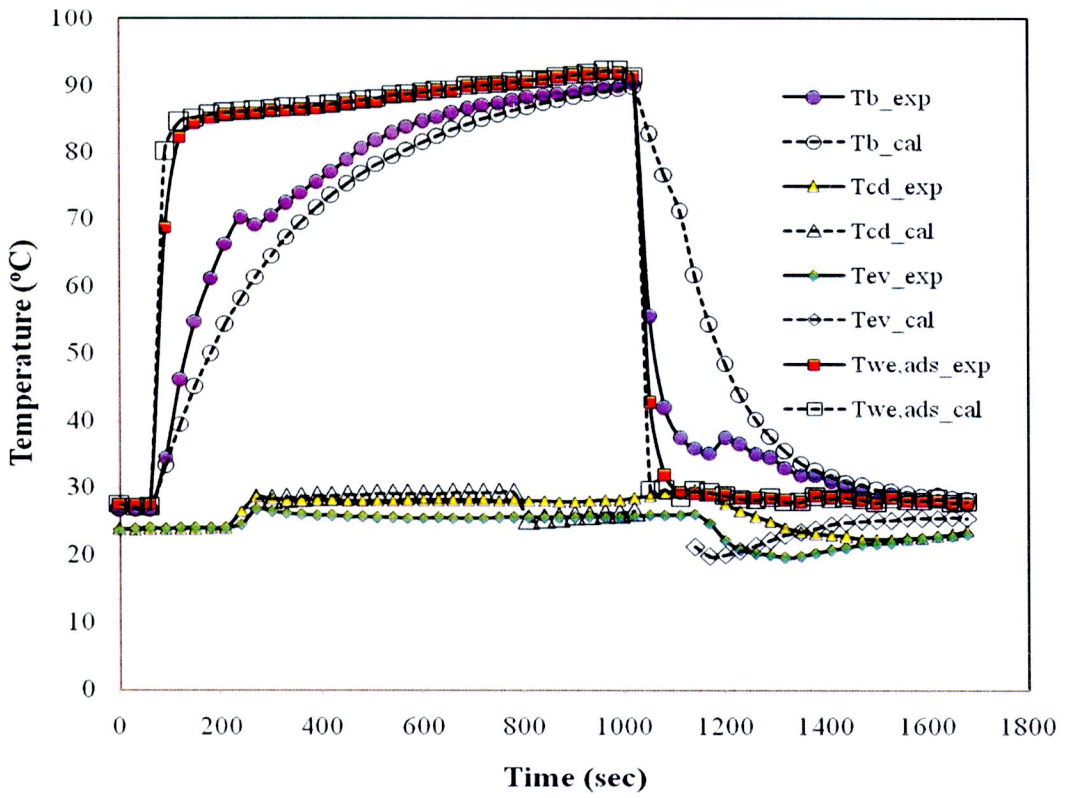

Figure 5.3. Temperature profiles of adsorption cooling system in the case of the sonic wave vibration at evaporator.

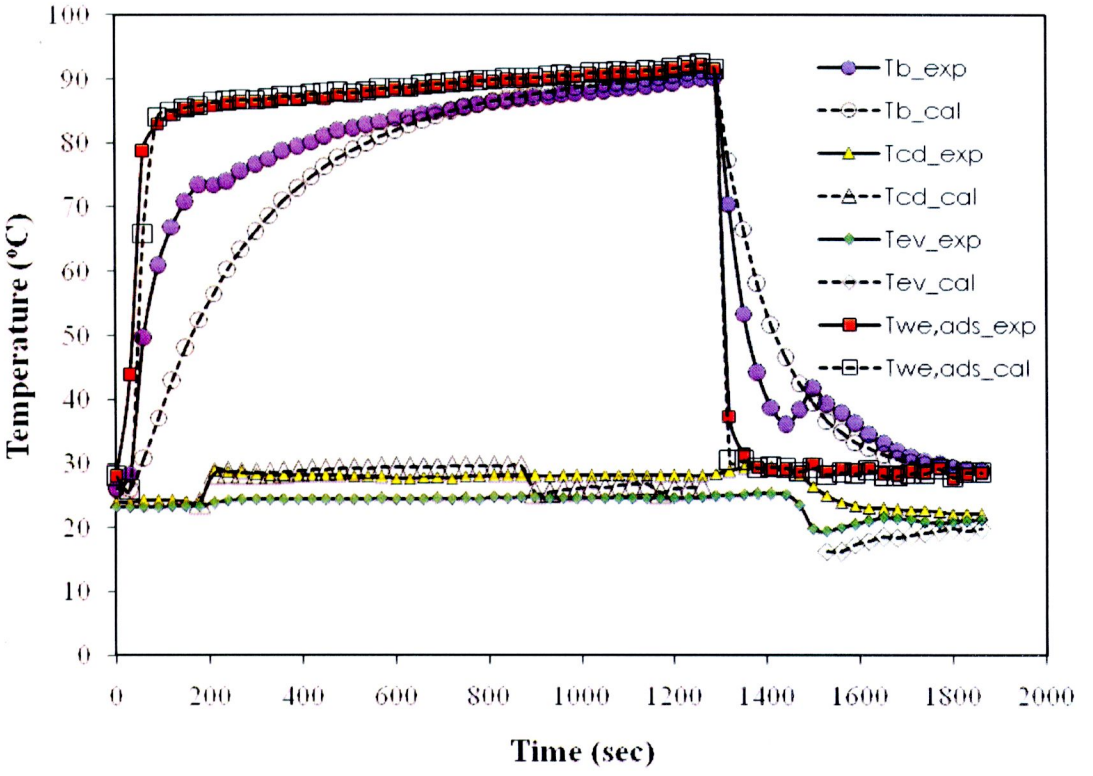

Figure 5.4. Temperature profiles of adsorption cooling system in the case of the sonic wave vibration at adsorber.