TABLE OF CONTENTS

	Page
Acknowledgement	iii
Abstract (English)	iv
Abstract (Thai)	vi
Table of contents	viii
List of tables	xii
List of figures	xiii
Abbreviations and Symbols	XV
CHAPTER 1 INTRODUCTION	1
1.1 Statement and significance of the problem	~1
1.2 Literature review	2
1.2.1 Experimental work and prototype demonstration	3
1.2.2 Modeling and simulation works	5
1.2.3 Application of adsorption system	7
1.2.3.1) Air-conditioning	7
1.2.3.2) Adsorption chiller	8
1.3 Objective of the study	11
1.4 Scopes and methodology	12
1.4.1 Research scope	12
1.4.2 Research methodology	13
1.5 Expected benefits	14
CHAPTER 2 THEORY AND METHODOLOGY	15
2.1 Theory	15
2.1.1 Introduction	15
2.1.2 Adsorption refrigeration cycle	17
2.1.3 Inception of sonic wave	24
2.1.4 Working pairs	25
2.1.5 Heat source and heat sink	27

2.1.5.1) Waste heat	28
2.1.5.2) Renewable energy sources	28
2.2 Methodology	29
2.2.1 Compilation of all relevant information	29
2.2.2 Design, fabrication, assembly, installation, and	
preliminary testing, on	29
2.2.2.1) Adsorber	31
2.2.2.2) Evaporator and condenser	31
2.2.2.3) Thermosyphon heat pipe	31
2.2.2.4) Measurements	31
2.2.2.5) Experiment operation	32
CHAPTER 3 PERFORMANCE ANALYSIS OF A MODULAR	° 33
ADSORPTION COOLING SYSTEM HAVING	
SONIC VIBRATION AT EVAPORATOR	
3.1 Introduction	33
3.2 Experimental system design	33
3.2.1 Adsorber	34
3.2.2 Evaporator	35
3.2.3 Condenser	35
3.2.4 Instrumentation	35
3.2.4.1) Temperature	35
3.2.4.2) Pressure	35
3.2.4.3) Flow rate/Volume	36
3.3 Experimental procedure	36
3.3.1 Desorption process	36
3.3.2 Condensation process	36
3.3.3 Evaporation process	36
3.4 Experimental conditions	36
3.5 Results and discussion	37
3.5.1 Thermal behavior of the adsorber	37
3.5.2 Thermal behavior of the evaporator	40

3.5.3 Parameters affecting adsorption system performance	40
3.6 Performance comparison with previous works	44
3.7 Conclusion	46

CHAPTER 4 PERFORMANCE ANALYSIS OF A MODULAR 48 ADSORPTION COOLING SYSTEM WITH A SONIC VIBRATION IN THE ADSORBER

4.1 Introduction	48
4.2 Sonic wave inception	49
4.3 Experimental set-up	50
4.3.1 Adsorber	51
4.3.2 Condenser	51
4.3.3 Evaporator	51
4.3.4 Instrumentation	51
4.3.4.1) Temperature	51
4.3.4.2) Pressure	52
4.3.4.3) Flow rate	52
4.3.4.4) Methanol level	52
4.3.5 Operation	52
4.4 Results and discussion	53
4.4.1 Thermal behaviour of adsorption system	54
4.4.2 Parameters affecting adsorber performance	55
4.4.3 Effect of valve opening temperature	59
4.4.4 Parameters affecting evaporator performance	59
4.4.5 Performance comparison with previous work	61
4.5 Conclusion	62
CHAPTER 5 SYSTEM SIMULATION OF THE ADSORPTION	63
COOLING SYSTEM WITH SONIC VIBRATION	
AT EVAPORATOR AND ADSORBER	
5.1 Operation conditions and constants for simulation	63

5.2 Flow chart of simulation program for adsorption cooling system 64

Х

5.3 Verification of the simulation results	70
CHAPTER 6 CONCLUSION AND RECOMMENDATIONS	72
6.1 Conclusions	72
6.1.1 A modular adsorption cooling system having a sonic	
vibration at the evaporator	72
6.1.2 A modular adsorption cooling system having a sonic	
vibration at the adsorber	73
6.1.3 System simulation analysis	73
6.2 Recommendations	74
References	75
Appendices	78
Appendix A Experimental data	79
Appendix B List of pictures	95
Appendix C List of publications	101
Curriculum Vitae	159

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่ Copyright[©] by Chiang Mai University All rights reserved

LIST OF TABLES

Table	Page
2.1 Example refrigerant and special properties	25
2.2 Example refrigerant pairs and their heat adsorption	26
2.3 Suitable application ranges for adsorbent-adsorbate pairs	27
3.1 Summary of the testing conditions in this study	37
3.2 Performance comparison with previous work	46
4.1 Summary of the testing conditions in this study	53
4.2 Effect of valve opening temperature	58
4.3 Parameters affecting evaporator performance	60
4.4 Performance comparisons with previous work	61
5.1 The operating conditions of the adsorber, evaporator, condenser and	
sonic wave generator (sonic wave generator at the evaporator)	63
5.2 Constants for calculation (sonic wave generation at the evaporator)	65
5.3 The operating conditions of the adsorber, evaporator, condenser and	
sonic wave generator (sonic wave generator at the adsorber)	66
5.4 Constants for calculation (sonic wave generation at the adsorber)	67

LIST OF FIGURES

Figure	Page
1.1 Schematic diagrame of the air conditioner module	3
1.2 Schematic diagrame of the adsorption air conditioner installed	
in the locomotive	4
1.3 Schematic diagrame of the adsorption air conditioner	4
1.4 Schematic diagram of the compact adsorption room air conditioner	8
1.5 Schematic diagram of the heat-pipe type silica gel-water adsorption chi	ller 8
1.6 Schematic diagram of the heat-pipe combined evaporator	3 9
1.7 Schematic diagram of the air conditioner in the locomotive operator cal	pin 10
1.8 Schematic diagram of experimental set up	11
2.1 Basic operating principle of adsorption process	16
2.2 P-T-x diagram of an adsorption cycle	17
2.3 Solar cooling paths	29
2.4 Schematic sketchs of the experiment apparatus	30
3.1 Schematic sketchs of the experiment apparatus	34
3.2 Temperature profiles of the bed and the evaporator including the evapo	rator
circulating water	38
3.3 Cooling down time of activated carbon using various cooling methods	39
3.4 Temperature profiles of the adsorption system over time	ers 41
3.5 Relationship of COP, SCP and VCP with the heat source temperature	
without sonic wave	e ₄₂
3.6 Effect of cooling water temperature on system performance	
without sonic wave	43
3.7 The effect of the sonic wave on the heat of vaporization and the volume	etric
methanol production	44

3.8 Effect of the sonic wave on system performance	45
4.1 A schematic diagrame of the modular solid adsorption cooling unit	50
4.2 Temperature profiles of the adsorption system	55
4.3 Effect of the hot water temperature at the inlet of the adsorber	
on the volume of methanol condensate	56
4.4 Effect of the hot water temperature at the inlet of the adsorber	
on system performance	57
4.5 Effect of the hot water temperature in the adsorber on specific	
cooling power	57
4.6 Effect of the hot water temperature at the inlet of the adsorber	
on volumetric cold production	58
5.1 Flow chart for input and output data of the computer program	68
5.2 Flow chart of the simulation program for the adsorption cooling cycle	69
5.3 Temperature profiles of adsorption cooling system in the case of	
the sonic wave vibration at evaporator	70
5.4 Temperature profiles of adsorption cooling system in the case of	
the sonic wave vibration at adsorber	71

ลิขสิทธิ์มหาวิทยาลัยเชียงไหม Copyright[©] by Chiang Mai University All rights reserved

ABBREVIATIONS AND SYMBOLS

Nomenclature

A	Adsorption constant (-)
А	Area (m ²)
с	Specific heat (J/kg K)
СОР	Coefficient of performance (-)
dT	Temperature difference (°C)
dt	Time difference (s)
D	Diameter of adsorber (m)
ΔH	Heat of desorption and adsorption (J/kg)
k	Constant for working pair (-)
L	Latent heat of vaporization (J/kg)
m	Mass (kg)
Р	Pressure (Pa)
Q	Heat transfer (J)
R	Ideal gas constant of methanol (J/kg.K)
SCP	Specific cooling power (W/kg)
tang	Time (s)
Т	Temperature (°C)
<i>v</i> /righ	Overall heat transfer coefficient (kW/m ² K)
x	Concentration (kg _{adsorbate} /kg _{adsorbent})
V	Volume (cm ³)
VCP	Volumetric capacity power (cm ³ /W)

Subscript

а	Adsorption
ads	Adsorber
ac / b	Activated carbon
cond	Condenser
сw	Cooling water
d	Desorption
evap	Evaporator
hw	Hot water
in	Inlet
max	Maximum
met	Methanol
min	Minimum
out	Outlet
p	Isobaric process
S	Saturated
sonic	Sonic wave
ν	Isometric process
w	Water
wi	Inlet water
Superscript	
n	Constant for working pair (-)

Conversion by Chiang Mai University ρ Density (kg/m³) Density (kg/m³)