

## LIST OF CONTENT

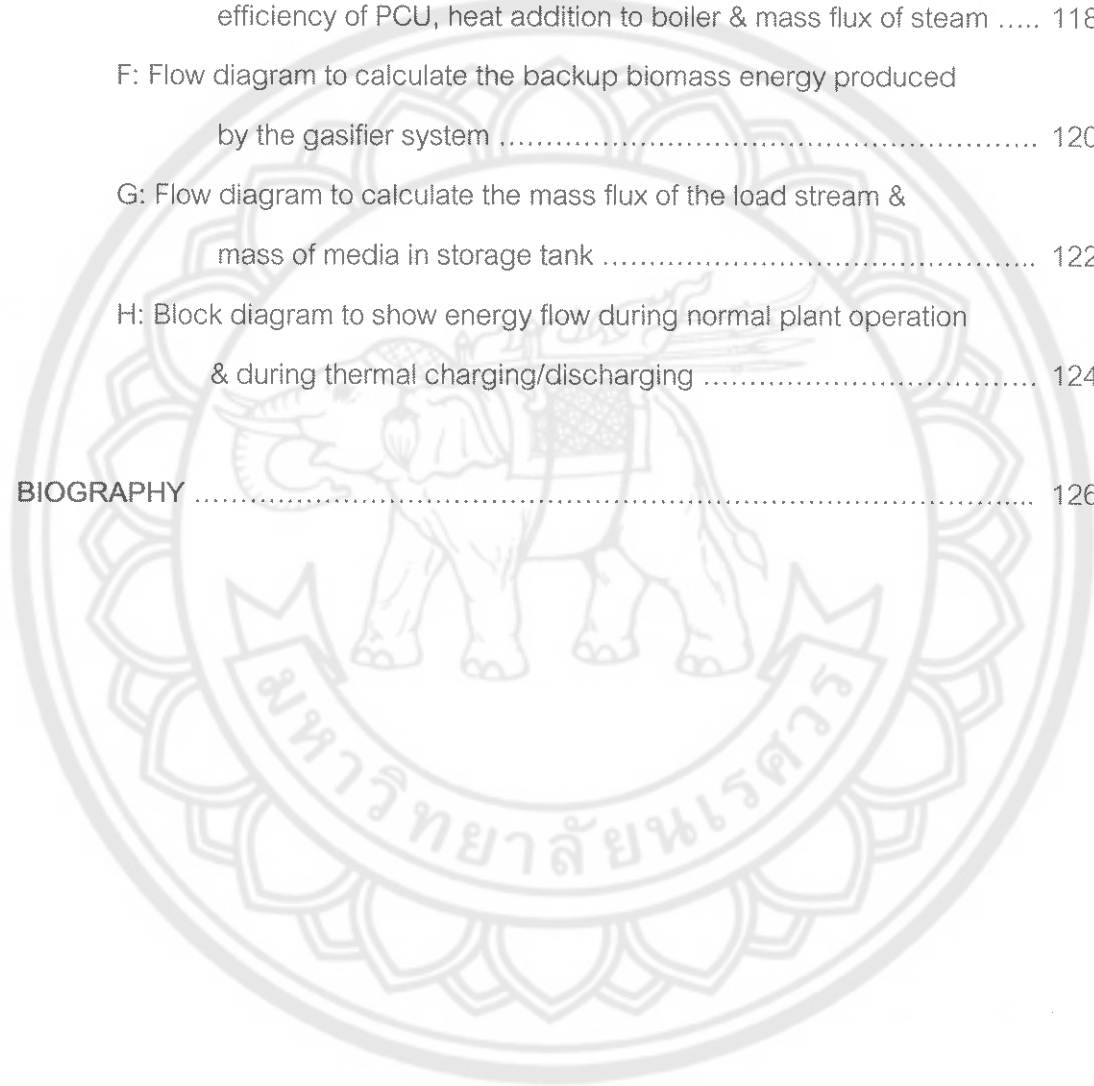
Chapter	Page
<b>I INTRODUCTION</b> .....	1
Brief Review of Energy Situation .....	1
Outline of Thailand's Power Sector .....	3
Statement of the Problem .....	5
Rationale of the Study .....	6
Purpose of the Study .....	7
Scope of the Study .....	7
Limitations of the Study .....	8
Location of the Study .....	9
<b>II REVIEW OF RELATED LITERATURE AND RESEARCH</b> .....	11
Solar Thermal/Biomass Power Production (Europe, USA) .....	11
Solar Thermal/Biomass Power Production (Other countries) .....	20
Solar Thermal/Biomass Power Production (Thailand) .....	24
Simulation Modeling of the Solar Parabolic Trough Collector and Power Plant .....	26
<b>III METHODOLOGY</b> .....	30
Design and Description of Proposed Solar Power Plant .....	30
Development and Explanation of Mathematical Model .....	38
Solar Radiation (SR) Model of Phitsanulok Province .....	46
Thermodynamic Analysis and Calculation .....	55
Construction and Installation of Solar Parabolic Trough at SERT .....	75
Data Collection and Measurements .....	80

## LIST OF CONTENT (CONT.)

Chapter	Page
<b>IV RESULTS AND DISCUSSION</b> .....	83
Characteristic Curve of the Solar Trough Collector .....	83
Validation of the Collector System (CS) Model .....	84
Thermal Performance of Collector: Sunny vs. Partly Cloudy .....	86
Thermal Performance of Collector: Water vs. Mineral Oil .....	87
Analysis and Parametric Study of Proposed Solar Power Plant .....	89
Sensitivity Analysis of Parameter Change on Power Plant Performance .....	96
<b>V CONCLUSION AND RECOMMENDATION</b> .....	98
Conclusion .....	98
Recommendation .....	99
<b>REFERENCES</b> .....	100
<b>APPENDICES</b> .....	107
A: List of specifications, properties & operating conditions used for the simulation & calculations in this study .....	108
B: Flow diagram to calculate the daily average hourly direct radiation of a parabolic trough collector based on "average radiation" method (for partly cloudy condition) .....	112
C: Flow diagram to calculate the daily average hourly direct radiation of a parabolic trough collector based on "clear sky radiation" method (for sunny condition) .....	114
D: Flow diagram to calculate the fluid exit temperature, useful gain & instantaneous efficiency of the parabolic trough collector.....	116

## LIST OF CONTENT (CONT.)

Chapter	Page
E: Flow diagram to calculate the thermal efficiency of the Rankine cycle, efficiency of PCU, heat addition to boiler & mass flux of steam .....	118
F: Flow diagram to calculate the backup biomass energy produced by the gasifier system .....	120
G: Flow diagram to calculate the mass flux of the load stream & mass of media in storage tank .....	122
H: Block diagram to show energy flow during normal plant operation & during thermal charging/discharging .....	124
BIOGRAPHY .....	126



## LIST OF TABLES

Table	Page
1 Characteristics of some commercial parabolic trough collectors .....	13
2 Typical gas composition for different fuel and reactor types .....	16
3 Survey of selected major TES systems .....	19
4 Recommended average day of each month & value of n .....	47
5 Monthly average daily global radiation on a horizontal surface .....	48
6 Charging and discharging processes of thermal energy storage (sunny) ....	70
7 Charging and discharging processes of thermal energy storage (partly cloudy) .....	70
8 Main physical parameters of the LS-2, LS-3 and EPC .....	76
9 List of material for main components of EPC module .....	78
10 Instruments of the monitoring system and parameter measured .....	82
11 Summary of ave fluid temperatures: sunny and partly cloudy conditions .....	85
12 Summary of average fluid inlet and exit temperatures: water vs. mineral oil ..	88
13 Calculation of fluid mass flux and temperature in/out of boiler (sunny) .....	90
14 Calculation of fluid mass flux and temperature in/out of boiler (partly cloudy).....	90
15 Biomass energy needed for backup in partly and fully cloudy conditions ....	94
16 Comparison of solar and hybrid modes by LEC analysis .....	96
17 Effect of parameter change on power output .....	97

## LIST OF FIGURES

Figure	Page
1 R/P ratios of global crude oil, natural gas and coal (at end of 2004) .....	1
2 World consumption of fossil fuel, 1995 – 2004 .....	2
3 World energy consumption with projections to 2025 .....	2
4 World energy consumption: mature vs emerging economies .....	3
5 Power production and supply in Thailand .....	4
6 Block diagram of a basic BSPP system .....	6
7 Map of Thailand showing Phitsanulok province .....	9
8 Location of the Energy Park at SERT in Naresuan University .....	10
9 One of the SEGS plants in California, USA .....	13
10 Schematic diagram of the DISS test-loop in PSA .....	14
11 Three possible designs of a biomass electric generating system .....	15
12 Schematic of sugarcane leaf-bagasse gasifier system .....	22
13 Gasifier system installed in Maharashtra, India .....	23
14 Overall flow and energy transfer of the proposed BSPP .....	31
15 Section of a parabolic trough concentrator .....	32
16 A 4-piston steam engine coupled with generator .....	33
17 Basic layout of a small-scale biomass solar power plant (BSPP) .....	35
18 Block diagram of a BSPP mathematical model .....	40
19 Input & output variables of the CS Model (HTF: oil) .....	41
20 Input & output variables of the CS Model (HTF: water) .....	42
21 Input & output variables of the GS Model .....	43
22 Input & output variables of the TES Model .....	43
23 Input & output variables of the PCU Model .....	45
24 Input & output variables of the SR Model .....	46
25 Monthly average hourly direct radiation of Phitsanulok (partly cloudy) .....	51

## LIST OF FIGURES (CONT.)

Figure	Page
26 Standard curve for daily average hourly direct radiation of Phitsanulok (partly cloudy) .....	52
27 Monthly average hourly direct radiation of Phitsanulok (sunny) .....	54
28 Standard curve for daily average hourly direct radiation of Phitsanulok (sunny) .....	55
29 Evaluation sections of a DISS collector .....	63
30 Sensible heat storage with thermal oil .....	67
31 Flow diagram and T-S diagram of a Rankine cycle .....	71
32 The complete EPC at the Energy Park .....	76
33 Each EPC collector module is consists of (a) endplates; (b) torque-box central frame; (c) receiver supports; (d) cantilever arms; and (e) trough-base .....	77
34 Torque-box central framework .....	78
35 Setting the parabolic curve .....	78
36 Cantilever arm .....	78
37 Assembly of cantilever arm & framework .....	78
38 A partially-assembled module .....	79
39 Receiver under alignment testing .....	79
40 Temperature measured at receiver .....	79
41 Installation of the EPC at SERT .....	79
42 Steam produced by the EPC collector .....	79
43 Solar trough test-loop with computerised data monitoring and acquisition system .....	81
44 Magnetic flowmeter (F1) .....	81
45 Pressure sensor (P1) .....	81

## LIST OF FIGURES (CONT.)

Figure	Page
46 Temperature sensor (T1) .....	81
47 Vortex flowmeter (F2) .....	81
48 Temperature sensor (T2) .....	82
49 Pyrheliometer .....	82
50 Characteristic curve of EPC collector .....	83
51 Exit temperature of EPC collector during sunny condition .....	85
52 Exit temperature of EPC collector during partly cloudy condition .....	85
53 Monthly useful gain of EPC collector: sunny vs. partly cloudy .....	86
54 Comparison of exit temperature: water vs. mineral oil .....	88
55 Optimal range of fluid mass flux for a 210 m <sup>2</sup> collector .....	92
56 Optimal range of fluid mass flux for a 355 m <sup>2</sup> collector .....	92

## ABBREVIATIONS



BSPP	Biomass-hybrid Solar Thermal Power Plant
CPS	Central Power Station
CSP	Concentrating Solar Power
DISS	Direct Solar Steam
DSG	Direct Steam Generation
EGAT	Electricity Generating Authority of Thailand
EPC	Energy Park Collector
HTF	Heat Transfer Fluid
IPP	Independent Power Producer
LEC	Levelized Electricity Cost
MEA	Metropolitan Electricity Authority
NU	Naresuan University
PCU	Power Conversion Unit
PEA	Provincial Electricity Authority
PSA	Plataforma Solar de Almeria
PTC	Parabolic Trough Collector
SEGS	Solar Electricity Generating System
SERT	School of Renewable Energy Technology
SM	Solar Multiple
SPP	Small Power Producer
TES	Thermal Energy Storage



## ABBREVIATIONS (CONT.)

$A_a$	Collector aperture area
$A_r$	Surface area of absorber
$A_c$	Surface area of glass cover
$C_g$	Geometric concentration ratio
$C_p$	Specific heat of fluid
$C_{th, min}$	Minimum thermal storage capacity, in hours
$D_c$	Glass cover diameter
$D_i$	Absorber inside diameter
$D_o$	Absorber outside diameter
$F_B$	Boiler heat removal factor
$F_R$	Collector heat removal factor
$G_{bc}$	Clear sky normal beam irradiance on a horizontal surface
$HHV_{gas}$	High heating value of producer gas
$H_i, H_o$	Specific enthalpies of fluid at collector inlet & outlet
$\bar{H}$	Monthly average daily global radiation of Phitsanulok
$h_i$	Heat transfer coefficient inside the absorber
$h_{rad, r-c}$	Radiation heat loss from absorber wall to glass cover
$h_{conv, r-c}$	Convection heat loss from absorber wall to glass cover
$h_{rad, c-a}$	Radiation heat loss from glass cover to the sky
$h_{wind}$	Convection heat loss to the ambient
$I_o$	Direct normal irradiance
$k$	Thermal conductivity of absorber
$k_{air}$	Thermal conductivity of air
$\bar{K}_T$	Average clearness index
$K_\theta$	Incidence angle modifier

## ABBREVIATIONS (CONT.)

$L_r$	Aperture (or receiver) length
$m_{fuel}$	Mass of solid biomass fuel
$m_{st}$	Mass of the storage medium
$(mC_p)_{st}$	Mass-specific heat product of the storage medium
$\dot{m}$	Mass flux of fluid
$\dot{m}_L$	Mass flux of the load stream
$\dot{m}_s$	Mass flux of steam
$N_u$	Nusselt number
$n$	Day of the year
$Pr$	Prandlt number
$P_{in}$	Process pressure at collector inlet
$P_{rated}$	Rated power of the electric generator
$Q_A$	Energy addition to the boiler of PCU
$Q_L$	Energy removal to the PCU
$Q_u$	Useful gain of collector
$Q_{u,bio}$	Useful energy from gasifier
$Re$	Reynolds number
$r_d$	Ratio of hourly total to daily total diffuse radiation
$r_l$	Ratio of hourly total to daily total global radiation
$S$	Absorbed radiation per unit aperture area
$T_{amb}$	Ambient temperature
$T_{bi}, T_{bo}$	Fluid temperature at boiler inlet & outlet
$T_{fi}, T_{fo}$	Fluid temperature at collector inlet & outlet
$T_c$	Temperature of glass cover

## ABBREVIATIONS (CONT.)

$T_r$	Temperature of absorber wall
$T_{sat}$	Saturation temperature of water at $P_{in}$
$T_{st, initial}$	Initial temperature of storage medium
$T_{st}$	Temperature of storage medium at the start of each finite time-interval
$T_{st}^*$	Temperature of storage medium at the end of each finite time-interval
$T_1, P_1$	Temperature & pressure of vapor (steam) at inlet of expander (engine)
$T_2, P_2$	Temperature & pressure of mixture at outlet of expander (engine)
$T_3, P_3$	Temperature & pressure of fluid (water) at outlet of condenser
$UA_B$	Overall heat transfer coefficient in the boiler heat exchanger
$U_L$	Overall heat loss coefficient
$U_o$	Overall heat transfer coefficient
$(UA)_{st}$	Loss coefficient – area product of storage tank
$V_{air}$	Velocity of air (wind speed)
$W$	Aperture width
$W - D_o$	Effective aperture
$Y_{gas}$	Yield of gas, in terms of $m^3$ per kg of solid fuel

## ABBREVIATIONS (CONT.)

$\eta_{aux}$	Efficiency of combustion
$\eta_{cycle}$	Thermal efficiency of the Rankine cycle
$\eta_E$	Efficiency of expander (engine)
$\eta_{gasifier}$	Efficiency of gasifier
$\eta_{gen}$	Efficiency of electric generator
$\eta_i$	Instantaneous thermal efficiency of collector
$\eta_o$	Optical efficiency of collector
$\eta_{pcu}$	Efficiency of PCU
$\eta_{total}$	Overall solar-to-electric efficiency
$\cos \theta$	Cosine of the incidence angle
$\cos \theta_z$	Cosine of the zenith angle
$\cos \omega_s$	Cosine of the sunset hour angle
$\delta$	Declination angle
$\psi$	Latitude of Phitsanulok
$\lambda$	Altitude of Phitsanulok
$\alpha$	Absorptance of absorber
$\varepsilon_r$	Emittance of absorber
$\tau$	Transmittance of glass cover
$\varepsilon_c$	Emittance of glass cover
$\rho$	Specular reflectance
$\gamma$	Intercept factor
$\mu_{air}$	Kinematic viscosity of air
$\mu_w$	Kinematic viscosity of water