REFERENCES

[1] Eugene D. Coyle, Richard A. Simmons , Understanding the Global Energy Crisis, Purdue University

[2] Statistical Digest 2015, Ceylon Electricity Board, Colombo 02, Sri Lanka, online www.ceb.lk/publications

[3] CEB Long Term Generation Expansion Plan 2015-2035, Retrieved online from web site; www.ceb.lk/publications

 [4] Sustainable Energy Authority, Sri Lanka Energy Balance 2014 Report, An Analysis of the Energy Sector Performances

[5] Ceylon Electricity Board, Non Conventional Renewable Energy (NCRE) Sector Development in Sri Lanka, Retrieved from web site: http://www.ceb.lk/do-business-with-us/

[6] Central Banka of Sri Lanka, Annual Report 2015

[7] M.M. El Wakil, Book of Power Plant Technology, International Edition; New Delhi, India TATA McGraw-Hill; 1988.

[8] C.J. Roos, *An overview of WHR technologies for moderate temperatures less than $1000ºF$;* U.S. Department of Energy; October 2013.

[9] Kalina AI. Generation of energy by means of a working fluid, and regeneration of a working fluid. United States Patent 4346561. Filed date: Aug. 31, 1982.

[10] Kalina AI. Combined cycle and waste heat recovery power systems based on a novel thermodynamic energy cycle utilizing low-temperature heat for power generation. American Society of Mechanical Engineers, 1983, New York, Paper No. 83-JPGC-GT-3, 1–5.

[11] Ahmed Elsayed, Mebrahtu Embaye, Raya AL-Dadah, Saad Mahmoud and Ahmed Rezk, Thermodynamic performance of Kalina cycle system 11 (KCS11): feasibility of using alternative zeotropic mixtures, School of Mechanical Engineering, University of Birmingham, Edgbaston, Birmingham B15-2TT, UK

[12] Kalina AI. Combined-cycle system with novel bottoming cycle. ASME Journal of Engineering

[13] K. Deepak, A.V.S.S.K.S.Gupta, Thermal Performance of Geothermal Power Plant with Kalina Cycle System, Vol 4, No 02 (June 2014)

[14] Chengku Nie, Jialing Zhu, Xinshou Liang, Wei Zhang and Wencheng Fu, Analysis and Optimization of Kalina Cycle, GRC Transactions, Vol. 37, 2013.

[15] Sunil Macwan, *The Kalina Cycle,A major breakthrough in Efficient heat to power generation,* CHP 2013 & WHP 2013 Conference and trade show, October 8,2013.

[16] Jiacheng He, Chao Liu, Xiaoxiao Xu, Yourong Li, Shungying Wu and Jinliang Xu, Performance research on modified KCS (Kalina Cycle System) 11 without throttle valve, Energy 64 (2014) 389-397

[17] S. Gupta, *Thermal Performance of Geothermal Power Plant with Kalina Cycle System;* (International Journal of Thermal Technologies), Vol.4, No.2; 2014.

[18] Nasruddin, Usvika R, Rifaldi M, Noor A. Energy and exergy analysis of Kalina Cycle System (KCS) 34 with mass fraction ammonia-water mixture variation. J Mech Sri Technol 2009:23(7): 1871-6

[19] Zhang XX, He MG, Zhang Y. A review of research on the Kalina Cycle, Renew Sustain Energy Rev 2012;16(7):5309-18

[20] Hettiarachchi HDM, Golubovic M, Worek WM, Ikegami Y. The performance of the Kalina Cycle System 11 (KCS-11) with low-temperature heat sources Energy Resource Technology, 007;129(3):243e7.

[21] P.K.Nag, A.V.S.S.K.S. Gupta, Exergy Analysis of the Kalina Cycle, Applied Thermal Engineering Vol.18, No.6, pp.427-439,1998

[22] Convert Low grade Heat in to Electric Power, Thermodynamic Cycles for Conversion; Retrieve from web site: http://www.eng.usf.edu/~hchen4/index.htm

[23] Ian Smith, Nikola Stosic and Colin Aldis,Trilateral Flash Cycle System A high efficiency power plant resource for liquid resouces, City university , Loandon, EC IVOHB, U.K.

[24] Rumesh Fernando, Waste Heat Recovery of Thermal Power Stations using Organic Rankine Cycle.

[25] Kalina, I.A., Combined cycle system with novel bottoming cycle, *ASME Journal of Engineering for Gas Turbine and Power*, 106, 737-742, 1984.

[26] Mounir B. Ibrahim and Ronald M. Kovach, A Kalina cycle application for Power Generation, Energy Vol 18 No.9, pp.961-969, 1993

[27] Mingjun Wang, Annalisa Manera, Suizheng Qiu, G.H. Su, Ammonia-water mixture property code (AWProC) development verification and Kalina cycle design for nuclear power plant, Progress in nuclear energy 91 (2016) 26-37.

[28] Eva Thorin, Power Cycles with Ammonia-water mixtures as working fluid, Doctoral Thesis-2000, Royal Institute of Technology, Sweden.

[29] N.S. Ganesh, T. Srinivas, Design and Modeling of low temperature solar thermal power station, Applied Energy 91 (2012) 180-186

[30] N.S. Ganesh, T. Srinivas, Evaluation of Thermodynamic properties of ammonia-water mixture up to 100 bar for power application system, Journal of Mechanical Engineering Research Vol.3.(1), pp.25-39, January 2011.

[31] 'Heat Rates of Thermal Power Station in Sri Lanka', Public Utility Commission of Sri Lanka, January 2014.

[32] Flue gas property table – density, viscosity, Retrieved from the web site http://www.pipeflowcalculations.com/tables/flue-gas.php

[33] B. Ziegler, Ch. Trepp, Equation of state of ammonia-water mixture

[34] Prof. Pall Valdimarsson, ORC and Kalina Analysis and experience, Washington State University, Cooperative Extension Program

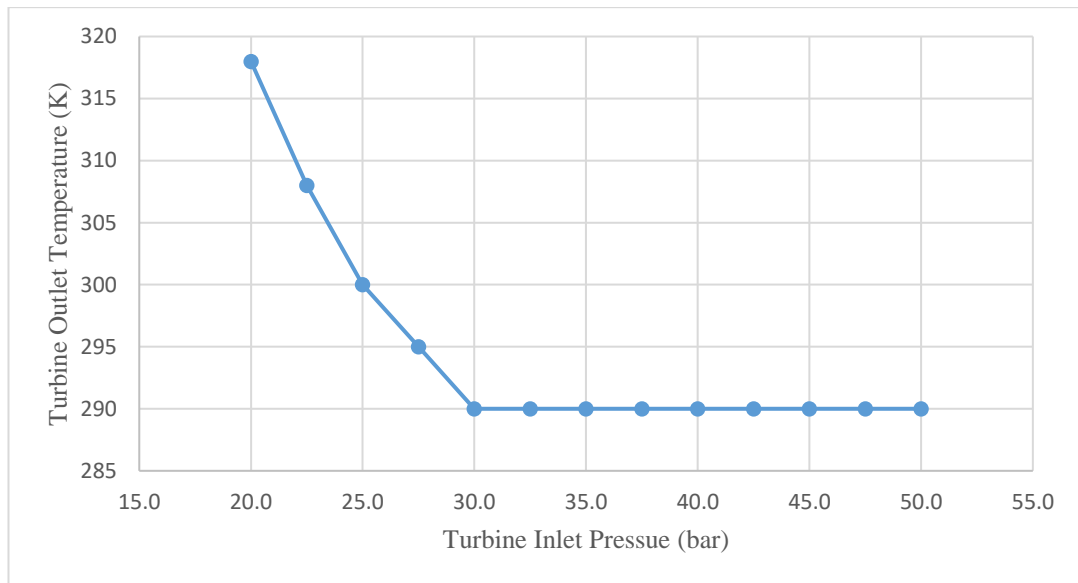# APPENDIX A: TEST RESULTS

Results for Model Test:

Figure A.1: Turbine Inlet Pressure vs Turbine Outlet Temperature of the model
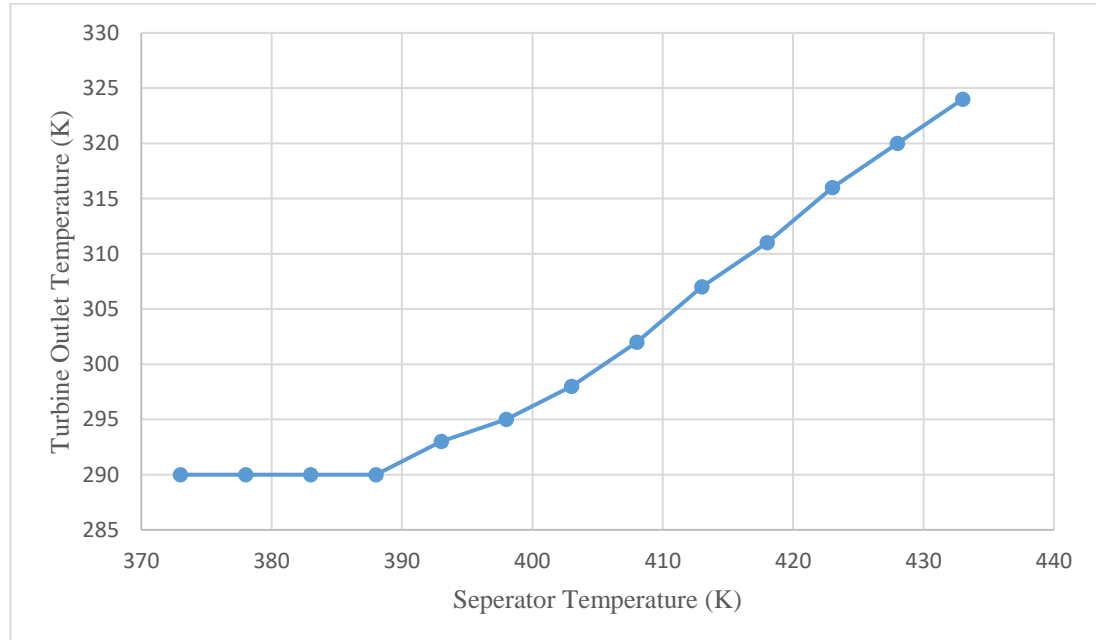

Figure A.2: Separator Temperature vs Turbine Outlet Temperature of the model
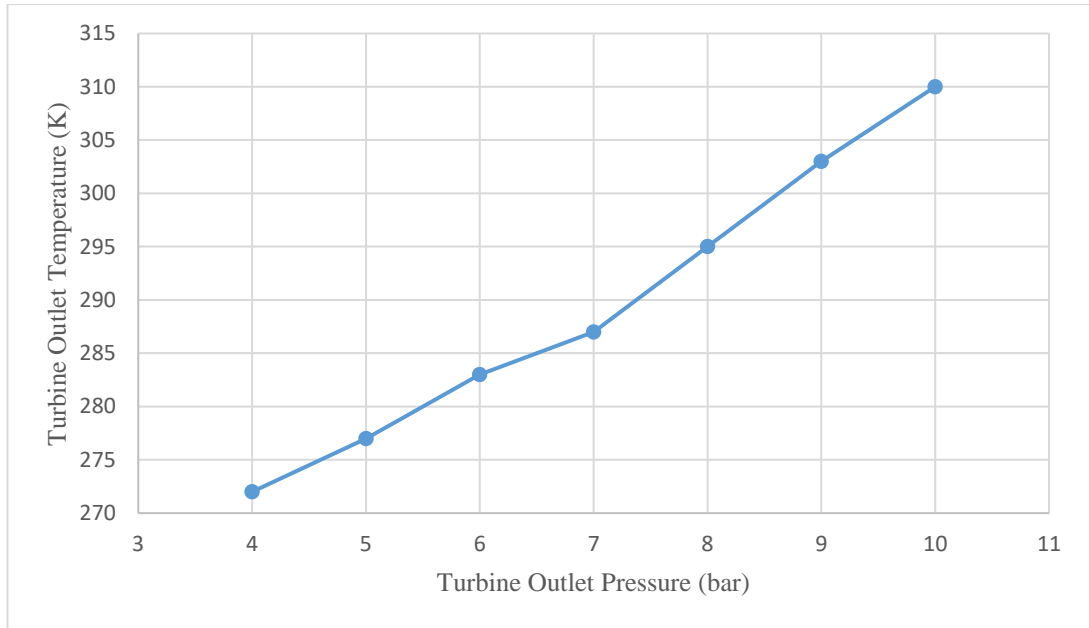
Figure A.3: Turbine Outlet Pressure vs Turbine Outlet Temperature of the model

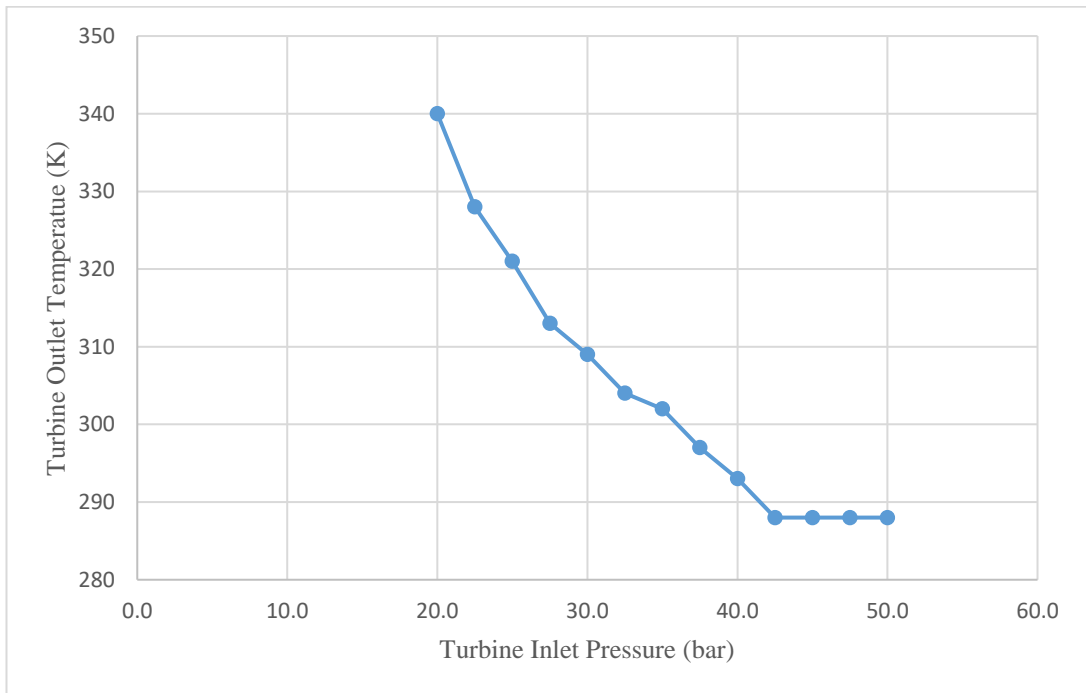**Results for Kelanitissa Combined Cycle Power Plant:**

Figure A.4: Turbine Inlet Pressure vs Turbine Outlet Temperature at KCCPP
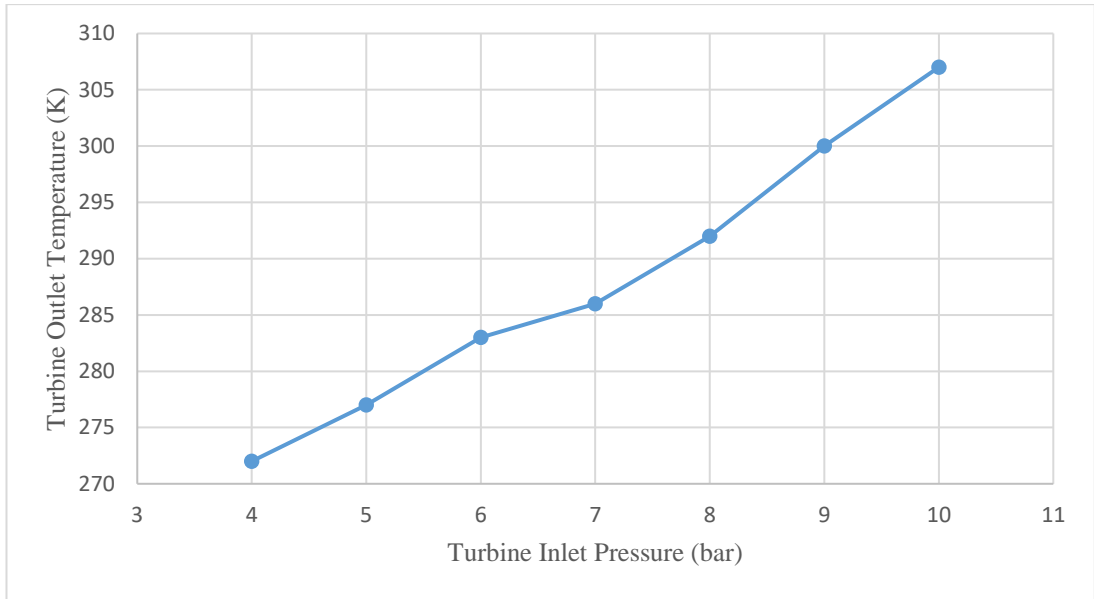
Figure A.5: Turbine Outlet Pressure vs Turbine Outlet Temperature of KCCPP

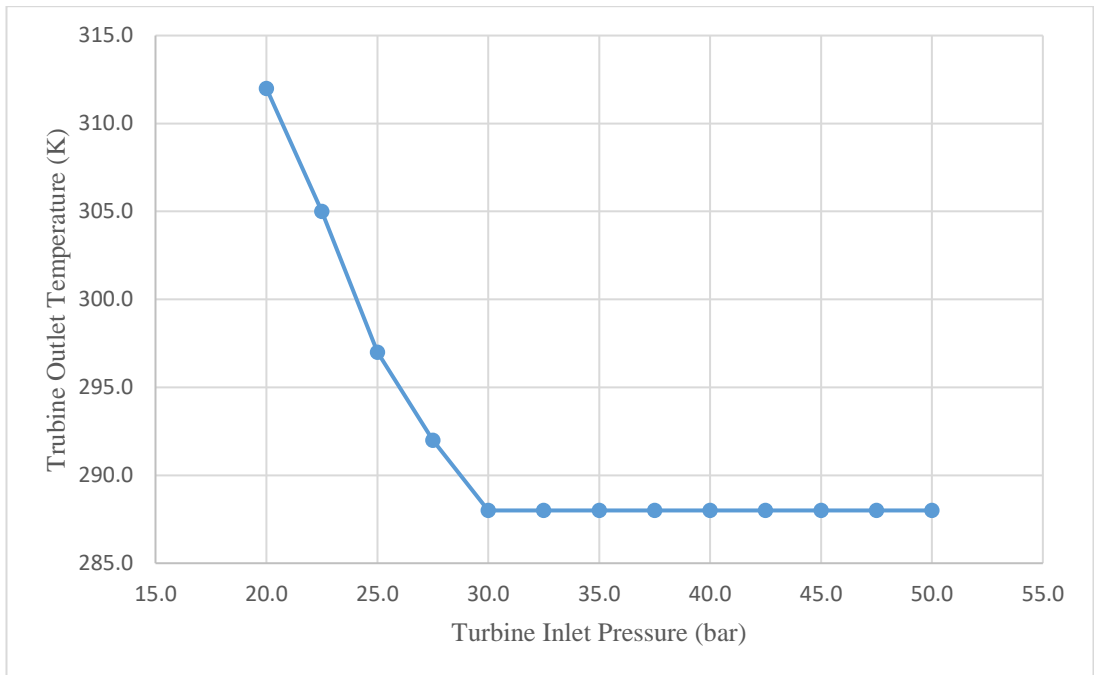**Results for Lakvijaya Power Plant:**

Figure A.6: Turbine Inlet Pressure vs Turbine Outlet Temperature of Lakvijaya
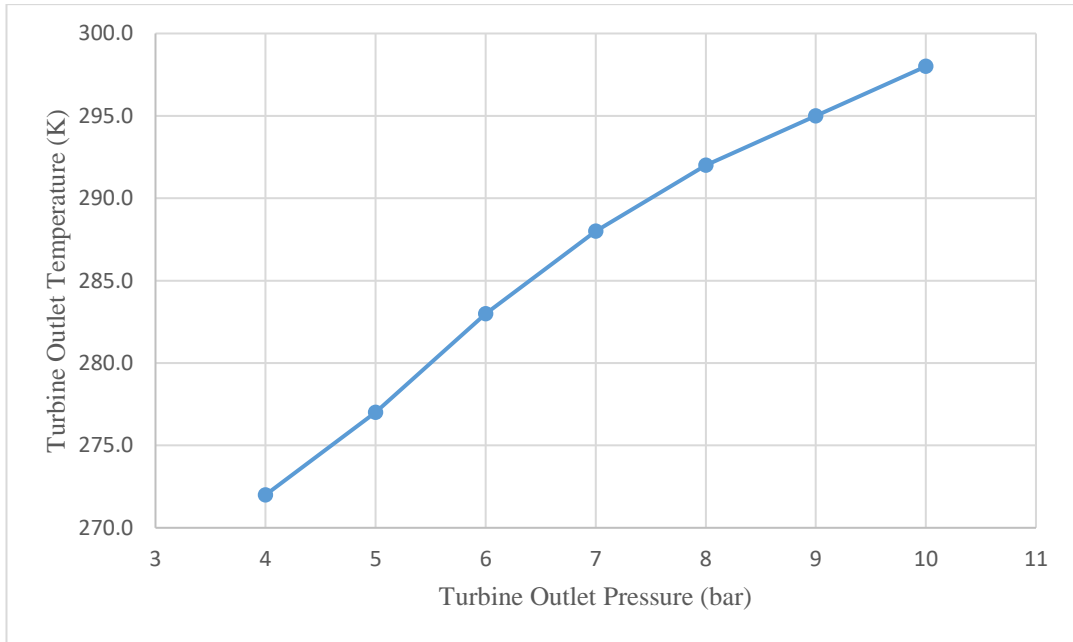Power Plant

Figure A.7: Turbine Outlet Pressure vs Turbine Outlet Temperature of Lakvijaya Power Plant

APPENDIX B: RELEVENT DIAGRAMS
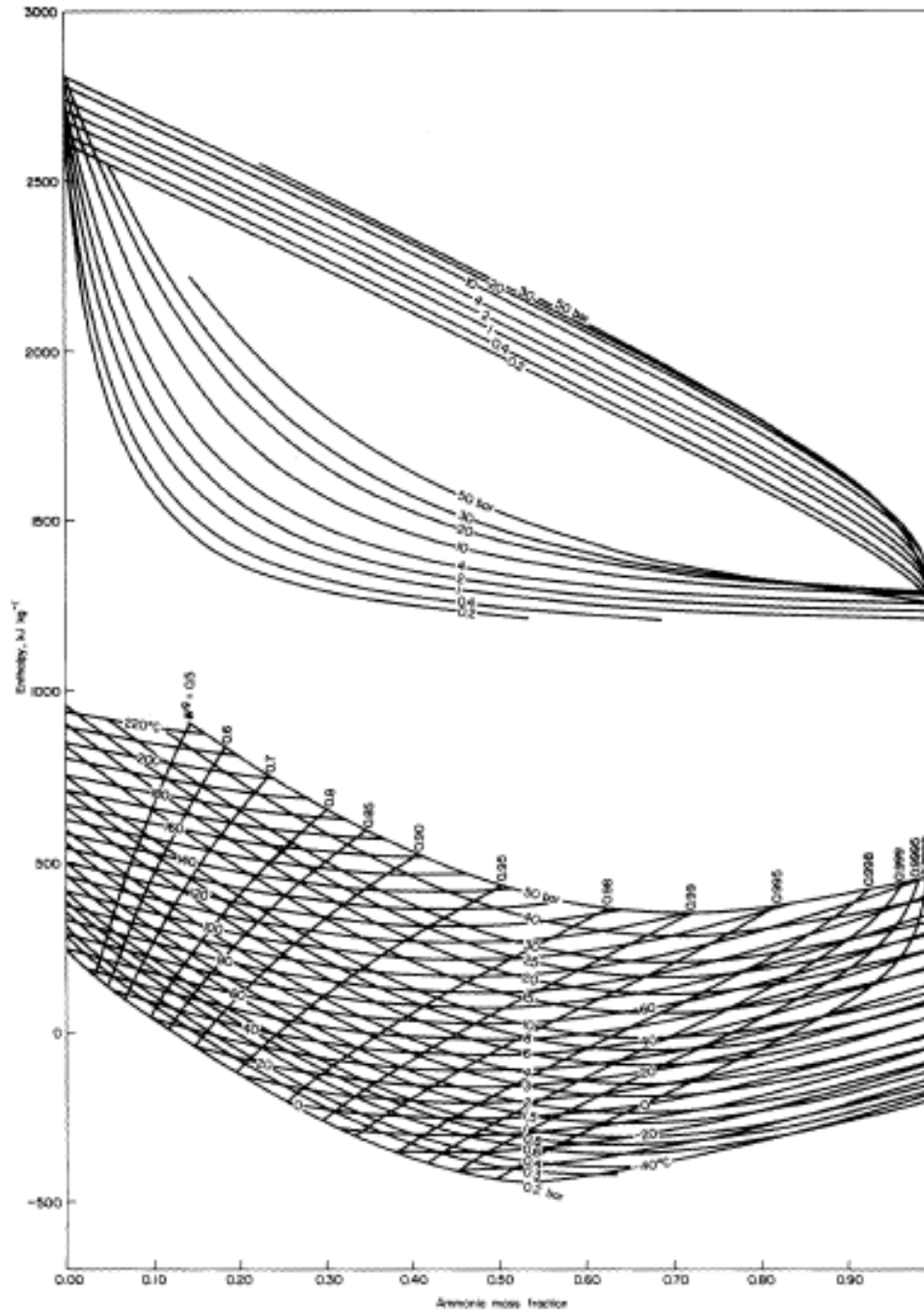
Ammonia mass fraction Vs Enthalpy diagram

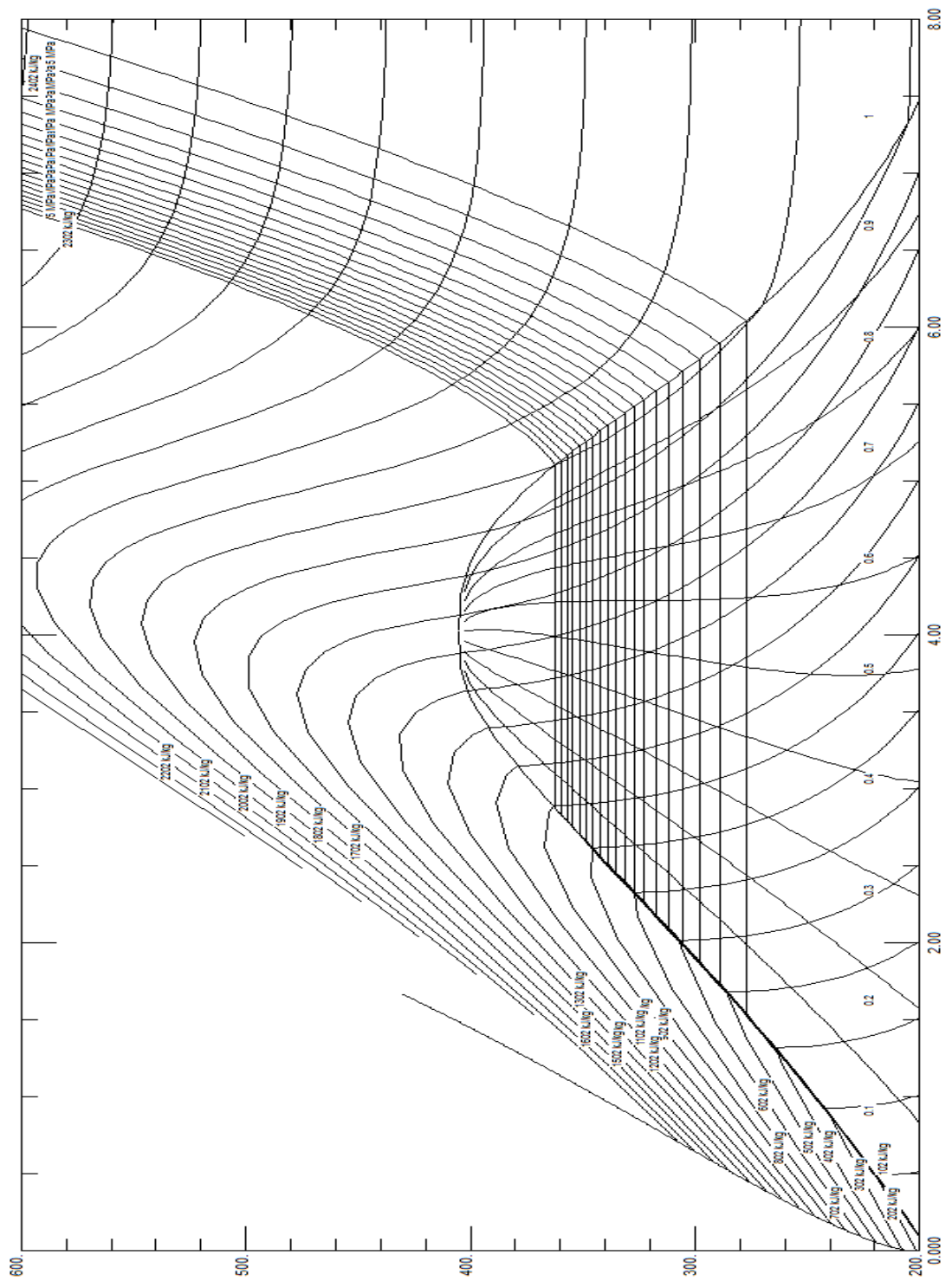Figure B.1

Temperature Vs Engtropy graph for Ammonia

Figure B.2

APPENDIX C: NET POSITIVE VALUE CALCULATIONS

Depends on the different tariff rates and expected running hours, the annual turnover would be changed. Following tables will illustrate the annual turnover of the selected plants under different scenarios.

Table C.1: Expected annual turnover at 60% running hours & Rs. 14.00/kWh

Waste Heat Recovery Opportunity	Exp. Elec. Output (kW)	Exp. Running Hours per year	Exp. Generation kW/yr	Unit Selling Price (Rs.)	Exp. Annual Turnover (Rs.)
KCCP	208.74	5256	1,097,137.44	14.00	15,359,924.16
Lakvijaya PS	520.12	5256	2,733,750.72	14.00	38,272,510.08

Table C.2: Expected annual turnover at 60% running hours & Rs. 15.00/kWh

Waste Heat Recovery Opportunity	Exp. Elec. Output (kW)	Exp. Running Hours per year	Exp. Generation kW/yr	Unit Selling Price (Rs.)	Exp. Annual Turnover (Rs.)
KCCP	208.74	5256	1,097,137.44	15.00	16,457,061.60
Lakvijaya PS	520.12	5256	2,733,750.72	15.00	41,006,260.80

Table C.3: Expected annual turnover at 60% running hours & Rs. 15.40/kWh

Waste Heat Recovery Opportunity	Exp. Elec. Output (kW)	Exp. Running Hours per year	Exp. Generation kW/yr	Unit Selling Price (Rs.)	Exp. Annual Turnover (Rs.)
KCCP	208.74	5256	1,097,137.44	15.40	16,895,916.58
Lakvijaya PS	520.12	5256	2,733,750.72	15.40	42,099,761.09

Table C.4: Expected annual turnover at actual running hours & Rs. 15.00/kWh

Waste Heat Recovery Opportunity	Exp. Elec. Output (kW)	Exp. Running Hours per year	Exp. Generation kW/yr	Unit Selling Price (Rs.)	Exp. Annual Turnover (Rs.)
KCCP	208.74	3504	731,424.96	15.00	10,971,374.40
Lakvijaya PS	520.12	7895	4,106,347.40	15.00	61,595,211.00

Net Positive Value (NPV) Calculations

NPV calculations were done under 07 scenarios to investigate the feasibility of implementing WHR systems in identified heat sources. The calculations are shown below.

Table C.5: Scenario 1 – Electricity unit selling price Rs. 14.00, Interest Rate 8%

WHR Opportunity	Total Investment Rs.	Total Overhead(OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Interest Rate %	NPV of Income	PV of Inv. After 5 years
KCCP	63,504,000	635,040	15,359,924	14,724,884	0.08	58,792,193	(4,711,807)
Lakvijaya PS	157,248,000	1,572,480	38,272,510	36,700,030	0.08	146,532,578	(10,715,422)

Table C.6: Scenario 2 – Electricity unit selling price Rs. 15.00, Interest Rate 8%

WHR Opportunity	Total Investment Rs.	Total Overhead(OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Interest Rate %	NPV of Income	PV of Inv. After 5 years
KCCP	63,504,000	635,040	16,457,062	15,822,022	0.08	63,172,744	(331,256)
Lakvijaya PS	157,248,000	1,572,480	41,006,261	39,433,781	0.08	157,447,652	199,652

Table C.7: Scenario 3 – Electricity unit selling price Rs. 15.40, Interest Rate 8%

WHR Opportunity	Total Investment Rs.	Total Overhead(OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Interest Rate %	NPV of Income	PV of Inv. After 5 years
KCCP	63,504,000	635,040	16,895,917	16,260,877	0.08	64,924,965	1,420,965
Lakvijaya PS	157,248,000	1,572,480	42,099,761	40,527,281	0.08	161,813,682	4,565,682

Table C.8: Scenario 4 – Electricity unit selling price Rs. 14.00, Interest Rate 10%

WHR Opportunity	Total Investment Rs.	Total Overhead(OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Interest Rate %	NPV of Income	PV of Inv. After 5 years
KCCP	63,504,000	635,040	15,359,924	14,724,884	0.10	55,818,896	(7,685,104)
Lakvijaya PS	157,248,000	1,572,480	38,272,510	36,700,030	0.10	139,121,988	(18,126,012)

Table C.9: Scenario 5 – Electricity unit selling price Rs. 15.00, Interest Rate 10%

Waste Heat Recovery Opportunity	Total Investment Rs.	Total Overhead(OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Interest Rate %	NPV of Income	PV of Inv. After 5 years
KCCP	63,504,000	635,040	16,457,062	15,822,022	0.10	59,977,910	(3,526,090)
Lakvijaya PS	157,248,000	1,572,480	41,006,261	39,433,781	0.10	149,485,055	(7,762,945)

Table C.10: Scenario 6 – Electricity unit selling price Rs. 15.00, Interest Rate 10%

WHR Opportunity	Total Investment Rs.	Total Overhead(OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Interest Rate %	NPV of Income	PV of Inv. After 5 years
KCCP	63,504,000	635,040	15,359,924	14,724,884	0.12	53,079,912	(10,424,088)
Lakvijaya PS	157,248,000	1,572,480	38,272,510	36,700,030	0.12	132,295,395	(24,952,605)

Table C.11: Scenario 7 – Electricity unit selling price Rs. 15.40, Interest Rate 8%

WHR Opportunity	Total Investment Rs.	Total Overhead(OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Interest Rate %	NPV of Income	PV of Inv. After 5 years
KCCP	63,504,000	635,040	11,263,944	10,628,904	0.08	42,438,133	(21,065,867)
Lakvijaya PS	157,248,000	1,572,480	63,237,750	61,665,270	0.08	246,211,542	88,963,542