List of References

[1.] Sri Lanka Sustainable Energy Authority, *Energy Balance Statistics 2013;* Retrieved from web site: http://www.info.energy.gov.lk/.

[2.] Sri Lanka Sustainable Energy Authority, *Sri Lanka Energy Balance 2013 Report, An Analysis of Energy Sector Performance.*

[3.] Public Utility Commission of Sri Lanka, *Heat Rates of Thermal Power Plants in Sri Lanka*; January 2014.

[4.] Ceylon Electricity Board, *Statistical Digest 2014*.

[5.] M.A. Korobistyne, *New & Advanced Energy Conversion Technologies, Analysis of Cogeneration, Combined and Integrated Cycles;*1998.

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

[7.] D. Sjoding, *Overview of Waste Heat Recovery for Power & Heat;* U.S. Department of Energy, Chicago; 2010.

[8.] C.J. Roos, *An overview of WHR technologies for moderate temperatures less than 1000^{O}F;* U.S. Department of Energy; October 2013.

[9.] N.N. Dhungel, *Combine Heat & Power Partnership, Waste Heat to Power Systems;* U.S. Environmental Protection Agency; May 2012.

[10.] W. Turner, *Energy Management Handbook, 5th Edition*; 2005.

[11.] Convert Low Grade Heat into Electric Power, *Thermodynamic Cycles for the Conversion*; Retrieved from web site: http://www.eng.usf.edu/~hchen4/index.htm.

[12.] B. Saadatfar, R. Fakhrai & T. Fransson, *Thermodynamic Vapor Cycles for Converting Low- to Medium-grade Heat to Power: A State-of-the-art Review and Future Research Pathways;* (Micro Journals), Vol. 2 Issue 1; 2014.

[13.] Learn Engineering, *Kalina Cycle*; Retrieved from Learn Engineering web site: http://www.learnengineering.org/2013/01/kalina-cycle-power-plant.html ; 2013.

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

[15.] M. Mirolli, H. Hjartarson, H. A. Mlcak & M. Ralph, *Testing and Operating Experience of the 2 MW Kalina Cycle Geothermal Power Plant in Húsavík, Iceland*; Retrieved from web site: http://www.ommi.co.uk/PDF/Articles/54.pdf ; 2002.

[16.] M.D. Miroll, *Kalina Cycle power systems in waste heat recovery applications*; Retrieved from web site:http://www.globalcement.com/magazine/articles/721-kalina-cycle-power-systems-in-waste-heat-recovery-applications ; 2012.

[17.] E. Thorin, *Power Cycles with Ammonia-Water Mixtures as Working Fluid: Analysis of Different Applications and the Influence of Thermo-physical Properties;* Royal Institute of Technology, Stockholm, Sweden; 2000.

[18.] K. Matsuda, *Low Heat Power Generation System*; (Chemical Engineering Transactions), Vol.35, ISBN 978-88-95608-26-6; ISSN 1974-9791; 2013.

[19.] W. Ferdinand, *Preliminary Study of Binary Power Plant Output Comparing ORC and Kalina for Low-Temperature*; Resources in Rusizi Valley, Burundi.

[20.] R.F. Steidel, D.H. Pankow and K.A. Brown, *The Empirical Modeling of a Lysholm Screw Expander;* Proc 18th Intersoc Energy Conversion Eng Conf., pp. 286-293; 1983.

[21.] S. Vijayaraghavan and D.Y. Goswami, *A combined power and cooling cycle modified to improve resource utilization efficiency using a distillation stage;* (Energy), vol. 31, pp. 1177-1196; 2006.

[22.] T. Heppenstall, *Advanced gas turbine cycles for power generation: A critical review*; (Applied Thermal Engineering), Vol. 18, page 837-846; 1998.

[23.] I. Smith, *Trilateral Flash Cycle System: A high Efficiency Power Plant for Liquid Resources;* (City University, London – U.K.), page 2109-2114; 1995.

[24.] C. Zamfirescu & I. Dincer, *Thermodynamic analysis of novel ammonia–water Trilateral Rankine cycle;* (Thermochemical), Act 477, page7–15; 2008.

[25.] P. Bombarda, C.M. Invernizzi & C. Pietra, *Heat recovery from Diesel engines: A thermodynamic comparison between Kalina and ORC cycles*; (Applied Thermal Engineering), Vol. 30, page 212–219; 2010.

[26.] S. Quoilin, *Sustainable Energy Conversion Through the Use of Organic Rankine Cycles for Waste Heat Recovery and Solar Application;* Presented to the Faculty of Applied Science of the University of Liege, Belgium; 2011.

[27.] S. Quoilin, S. Declaye, B.F. Tchanche & V. Lemort, *Thermo-economic optimization of waste heat recovery Organic Rankine Cycles;* (Applied Thermal Engineering), Vol. 31, page 2885-2893; 2011.

[28.] B.F. Tchanche, *Low Grade Heat Conversion into Power Using Small Scale Organic Rankine Cycle;* Agricultural University of Athens, AUA; 2011.

[29.] S. Jian & L. Wenhua, *Operation optimization of an organic Rankine cycle (ORC) heat recovery power plant;* (Applied Thermal Engineering), Vol. 31, page 2032-2041; 2011.

[30.] National Institute of Standards and Technology, *Chemistry Web Book: Thermodynamic Properties of Fluid Systems;* Retrieved from web site: http://webbook.nist.gov/chemistry/fluid/

[31.] P. Arvay, M.R. Muller, V. Ramdeen & G. Cunningham, *Economic Implementation of the Organic Rankine Cycle in Industry;* ACEEE Summer Study on Energy Efficiency in Industry; 2011.

[32.] P. Peterson, Introduction to Capital Budgeting: University of Florida; Retrieved from online web book: http://ceciliodaher.tripod.com/capital_budgeting.pdf

[33.] W.L. Silber, NPV Versus IRR; Retrieved from online web book: http://people.stern.nyu.edu/wsilber/NPV%20Versus%20IRR.pdf

Appendix A

DETAILS ON WASTE HEAT IN THERMAL POWER PLANTS

Waste heat details of Sapugaskanda Power Station

Table A.1: Exhaust gas temperatures and approximate waste heat energy

	Avg. Exhaust Gas Temp. (^{O}C)	Stack Temp. to be maintained (^{o}C)	Avg. Exhaust Gas Qty (kg/hr)	Specific Heat Capacity C_p (kJ/kgK)	Exhaust Energy at the Stack (kW)
A 01	430	180	140160	1.109	10799.13
A 02	440	180	140160	1.109	11231.10
A 03	440	180	140160	1.109	11231.10
A 04	430	180	140160	1.109	10799.13
B 01	427	180	79200	1.109	6029.02
B 02	430	180	79200	1.109	6102.25
B 03	430	180	79200	1.109	6102.25
B 04	420	180	79200	1.109	5858.16
B 05	435	180	79200	1.109	6224.29
B 06	445	180	79200	1.109	6468.38
B 07	439	180	79200	1.109	6321.93
B 08	435	180	79200	1.109	6224.29

Table A.2: Average jacket water temperatures and approximate waste heat energy

	Avg. Jacket Water Outlet Temp. (^{o}C)	Avg. Jacket Water Inlet Temp. (^{o}C)	Jacket Water Flow Rate (m^3/hr)	Specific Heat Capacity C_p (kJ/kgK)	Energy at Jacket Cooling Water (kW)
A 01	94	80	190	4.2	3103.33
A 02					
A 03					
A 04					
B 01	83	75	135.6	4.2	1265.6
B 02					
B 03					
B 04					
B 05					
B 06					
B 07					
B 08					

Table A.3: Average raw water temperatures and approximate waste heat energy

	Avg. Raw Water Outlet Temp. (^oC)	Avg. Raw Water Inlet Temp. (^oC)	Avg. Raw Water Temp. Diff. (^oC)	Raw Water Flow Rate (m^3/hr)	Specific Heat Capacity C_p (kJ/kgK)	Energy at Cooling Water (kW)
A 01	52.4	40	12.4	760	4.2	10994.67
A 02						
A 03						
A 04						
B 01	NA	NA	NA	NA	NA	NA
B 02						
B 03						
B 04						
B 05						
B 06						
B 07						
B 08						

Table A.4: Average charge air water temperatures and approximate waste heat energy

	Avg. Charge Air Cooling Water Outlet Temp. (^oC)	Avg. Charge Air Cooling Water Inlet Temp. (^oC)	Cooling Water Flow Rate (m^3/hr)	Specific Heat Capacity C_p (kJ/kgK)	Energy at Cooling Water (kW)
A 01	NA	NA	NA	NA	NA
A 02					
A 03					
A 04					
B 01	49	44	276.56	4.2	1613.27
B 02					
B 03					
B 04					
B 05					
B 06					
B 07					
B 08					

Waste heat details of Lakvijaya Coal Power Station

Table A.5: Exhaust gas temperatures and approximate waste heat energy

Plant	Avg. Exhaust Gas Temp. (^{O}C)	Stack Temp. to be maintained (^{o}C)	Avg. Exhaust Gas Qty (kg/hr)	Specific Heat Capacity C_p (kJ/kgK)	Exhaust Energy at the Stack (kW)
U 01	150	90	1,000,000	1.075	17916.67
U 02	150	90	1,000,000	1.075	17916.67
U 03	150	90	1,000,000	1.075	17916.67

Table A.6: Waste energy at continuous blow down from each unit

Plant	Blow Down Water Out Temp. (^{o}C) at 17.5Mpa	Assumed maintain Temp. (^{o}C) at 2.5MPa	Blow Down Flow Rate (kg/hr)	Enthaphy at T 275 ^{o}C, P 17.5MPa,h1 (kJ/kg)	Enthaphy at T 100 ^{o}C, P 2.5MPa,h2 (kJ/kg)	Energy at Blow Down Water (kW)
U 01	275	100	8700	1134	420.85	1723.45
U 02	275	100	8700	1134	420.85	1723.45
U 03	275	100	8700	1134	420.85	1723.45

Note: Following values were for above calculation,

Blow down details;

Feed water pressure for the drum 17.5 MPa at 275 ^{o}C.

Feed water rate for 300 MW, 870 tons/hr and continuous blow down rate is 1%.

Assumptions for calculation;

In heat recovery from blow down, pressurized water in the drum 17.5 MPa at 275 ^{o}C would be reduced to 2.5 MPa at 100 ^{o}C.

Waste heat details of Jaffna Power Station

Table A.7: Exhaust gas temperatures and approximate waste heat energy

	Avg. Exhaust Gas Temp. (^{O}C)	**Stack Temp. to be maintained (^{o}C)**	**Avg. Exhaust Gas Qty (kg/hr)**	**Specific Heat Capacity C_p (kJ/kgK)**	**Exhaust Energy at the Stack (kW)**
DG 01	413	240	6800	1.1307	369.49
DG 02	417	240	6800	1.1307	378.03
DG 03	420	240	6800	1.1307	384.44

Table A.8: Average jacket water temperatures of each generator

	Avg. Jacket Water Outlet Temp. (^{o}C)	**Avg. Jacket Water Inlet Temp. (^{o}C)**	**Jacket Water Flow Rate (m^3/hr)**	**Specific Heat Capacity C_p (kJ/kgK)**	**Energy at Jacket Cooling Water (kW)**
DG 01					
DG 02	96	46	NA	4.2	-
DG 03					

Note: Jacket water flow rates were not measured in the plant, also design references were not possible to find, hence waste energy could not calculated.

Waste heat details of Keravalapitiya Power Station

Table A.9: Exhaust gas temperatures at open cycle and approximate waste heat energy

	Avg. Exhaust Gas Temp. (^{O}C)	**Stack Temp. to be maintained (^{o}C)**	**Avg. Exhaust Gas Qty (kg/hr)**	**Specific Heat Capacity C_p (kJ/kgK)**	**Exhaust Energy at the Stack (kW)**
GT 01	505	160	1,512,000	1.1307	589818348
GT 02	510	160	1,512,000	1.1307	598366440
ST	NA				

Table A.10: Average close cooling water temperatures and waste energy

	Avg. Close Coolig Water Outlet Temp. (^{o}C)	**Avg. Close Cooling Water Inlet Temp. (^{o}C)**	**Close Cooling Water Flow Rate (m^3/hr)**	**Specific Heat Capacity C_p (kJ/kgK)**	**Energy at Close Cooling Water (kW)**
GT 01	48	35	720	4.2	39312.00
GT 02	48	35	720	4.2	39312.00
ST	NA				

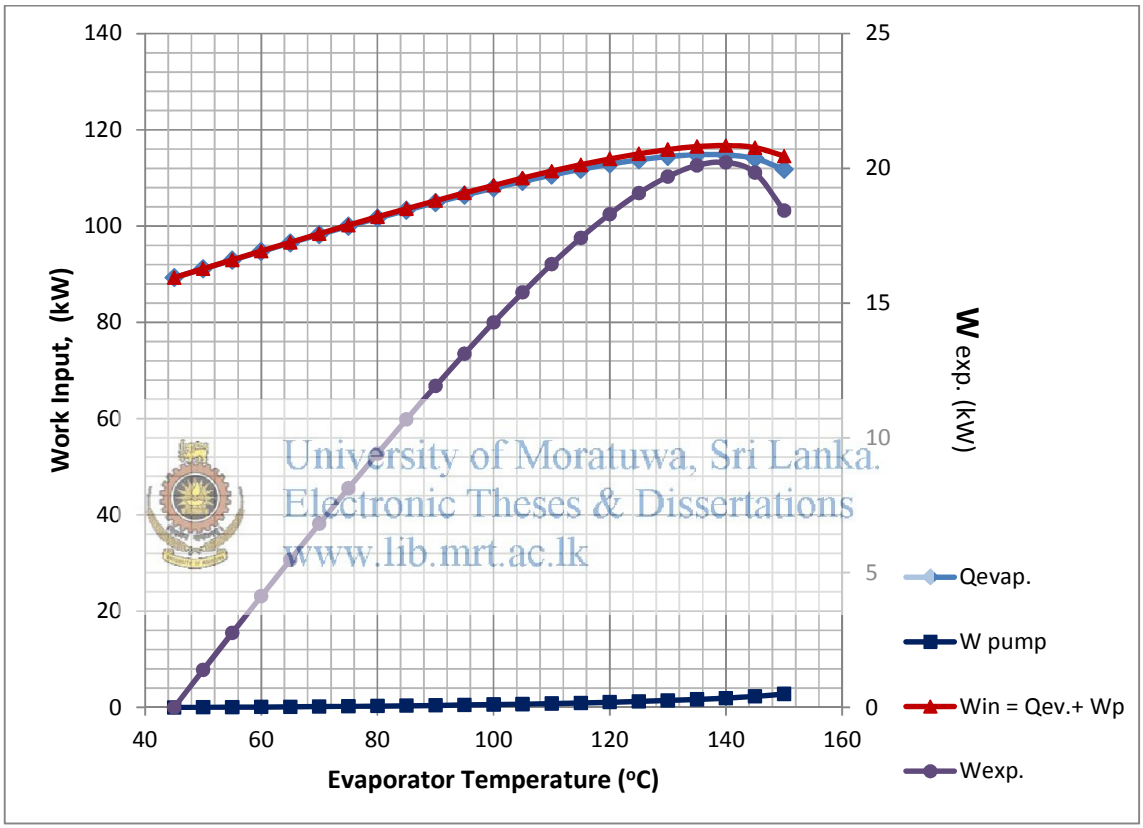
Table A.11: Average sea cooling water temperatures

	Sea Coolig Water Outlet Temp. (^{o}C)	**Sea Cooling Water Inlet Temp. (^{o}C)**	**Close Cooling Water Flow Rate (m^3/hr)**	**Specific Heat Capacity C_p (kJ/kgK)**	**Energy at Sea Cooling Water (kW)**
GT 01	38	32	1200	4.2	
GT 02	NA				
ST	38	32	20000	4.2	504000.00

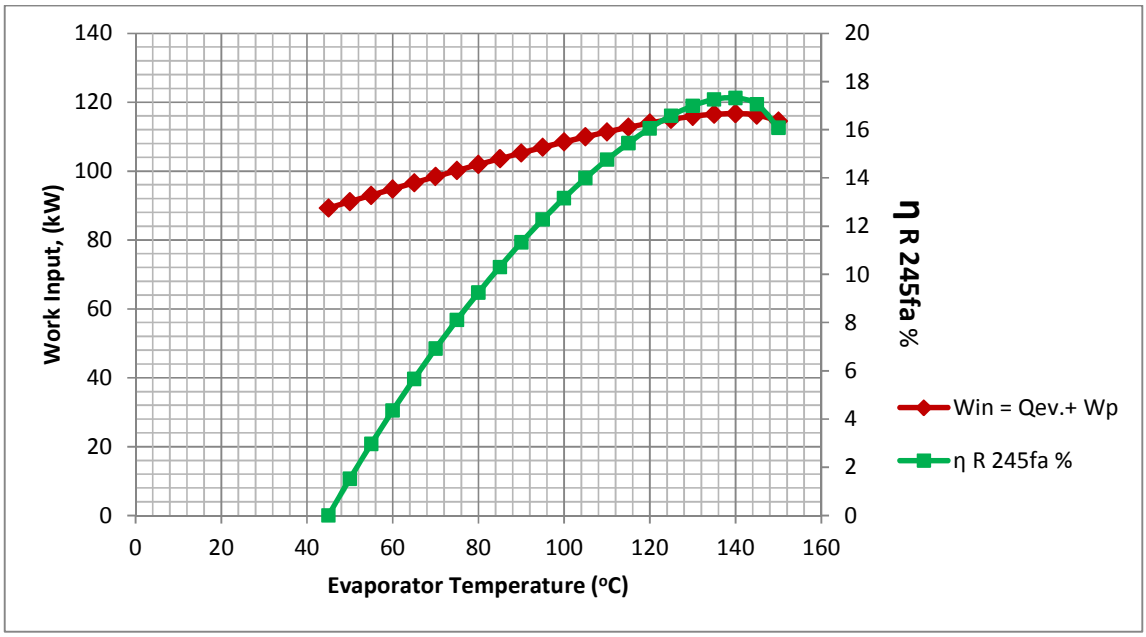
APPENDIX B

ORC PERFORMANCE ANALYSIS WITH EVAPORATOR TEMPERATURE VARIATION

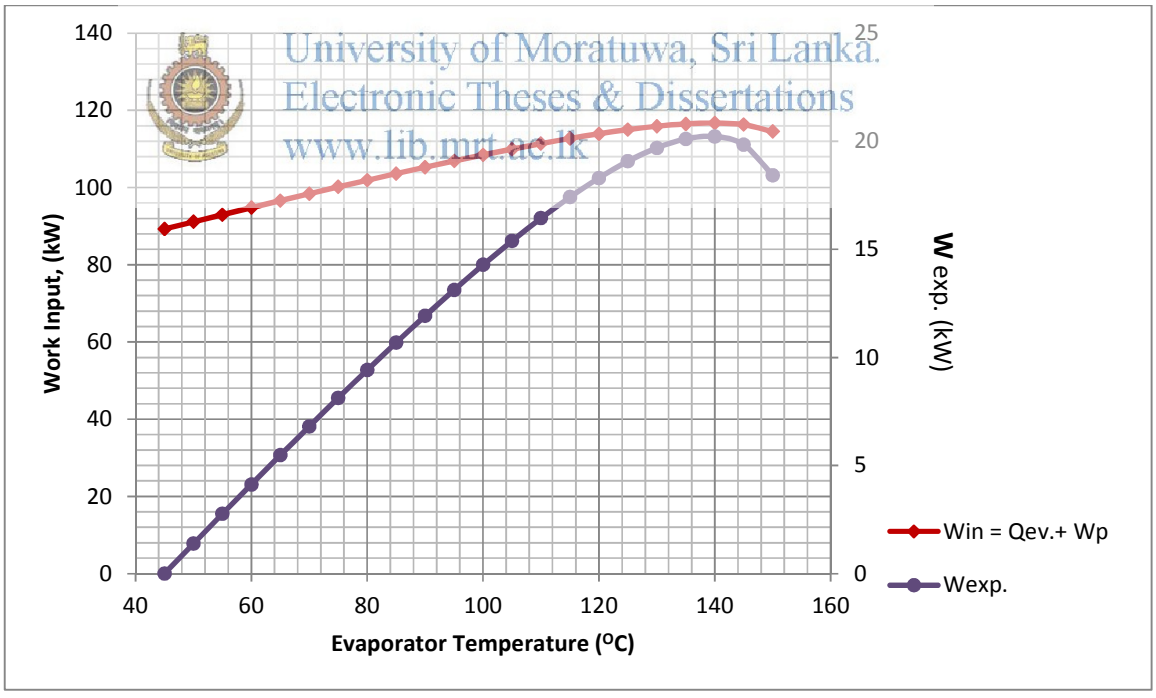
R245fa as working fluid



Graph B.1: Variation of Work component with different Evaporator temperatures for R245fa

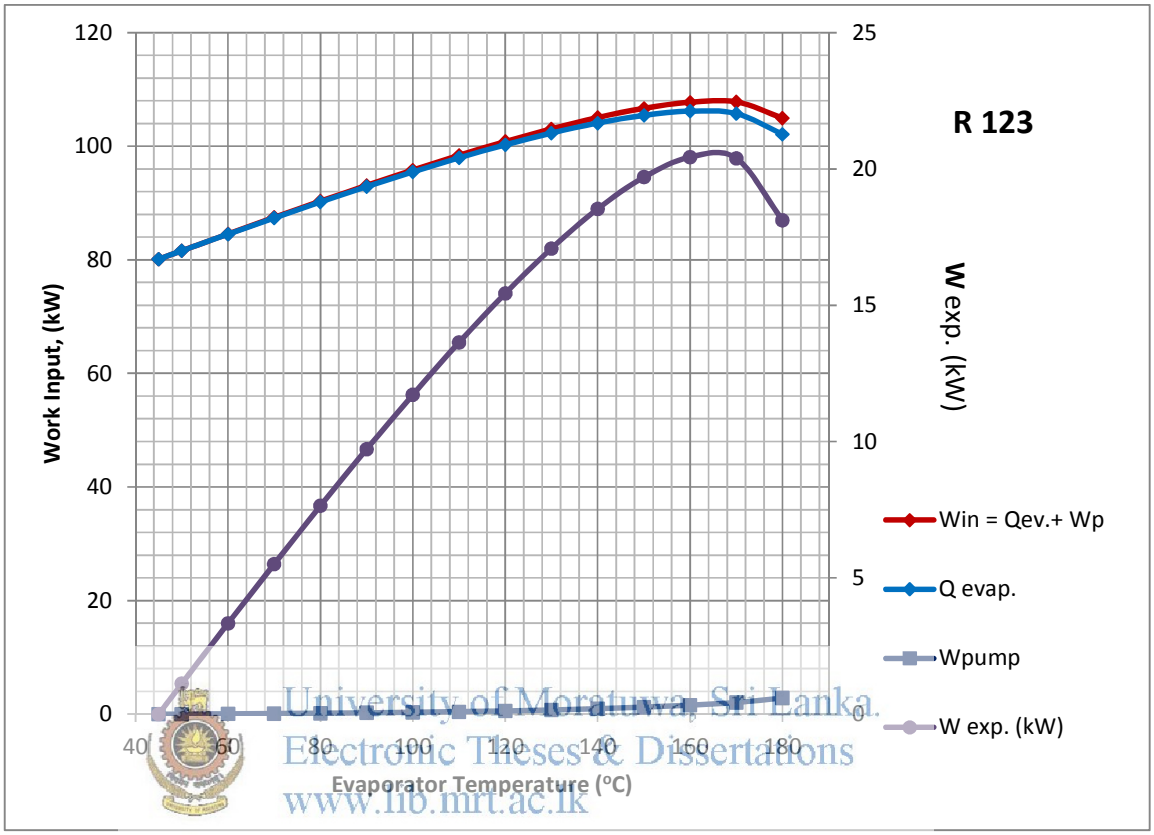


Graph B.2: Work Input and Efficiency variation with different Evaporator temperatures for R245fa

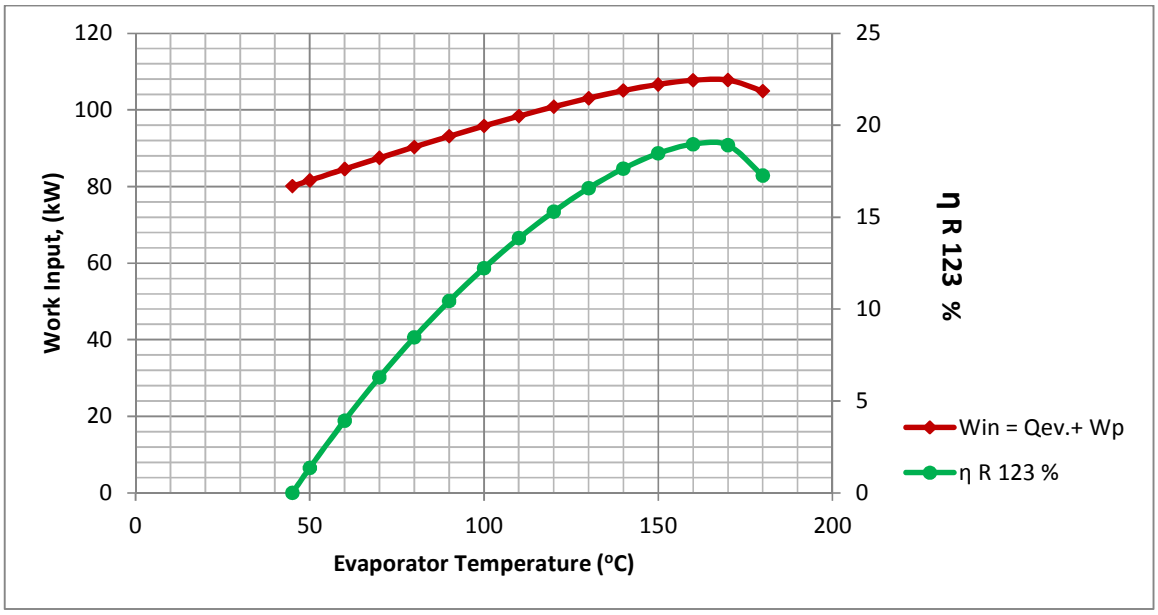


Graph B.3: Work Input and Work at Expander variation with different Evaporator temperatures for R245fa

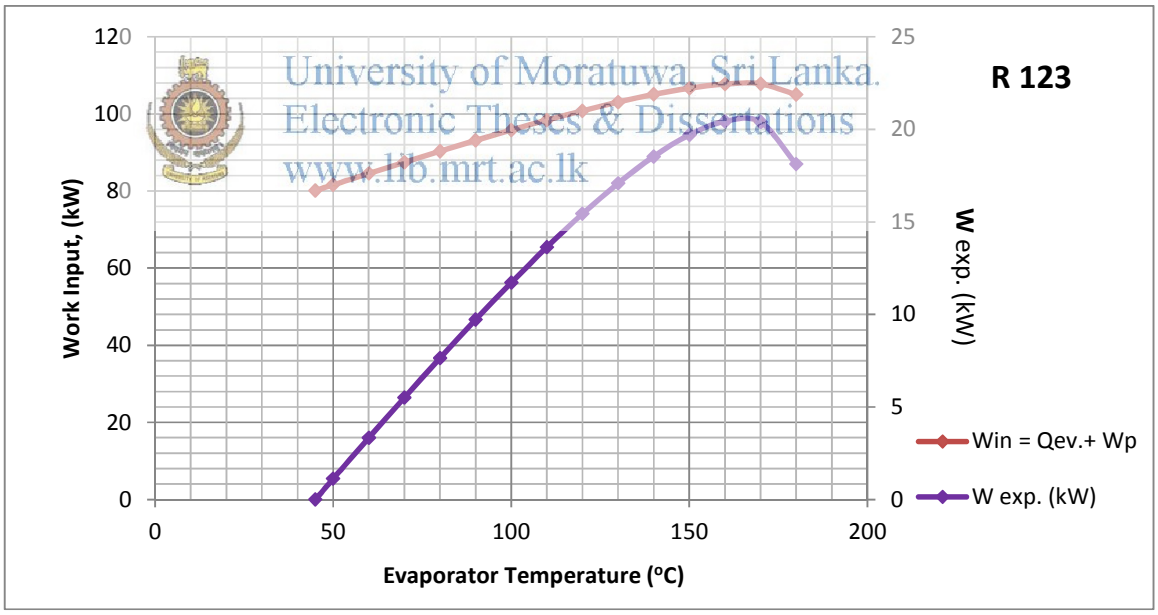
R123 as working fluid



Graph B.4: Variation of Work component in the cycle with different Evaporator temperatures for R123

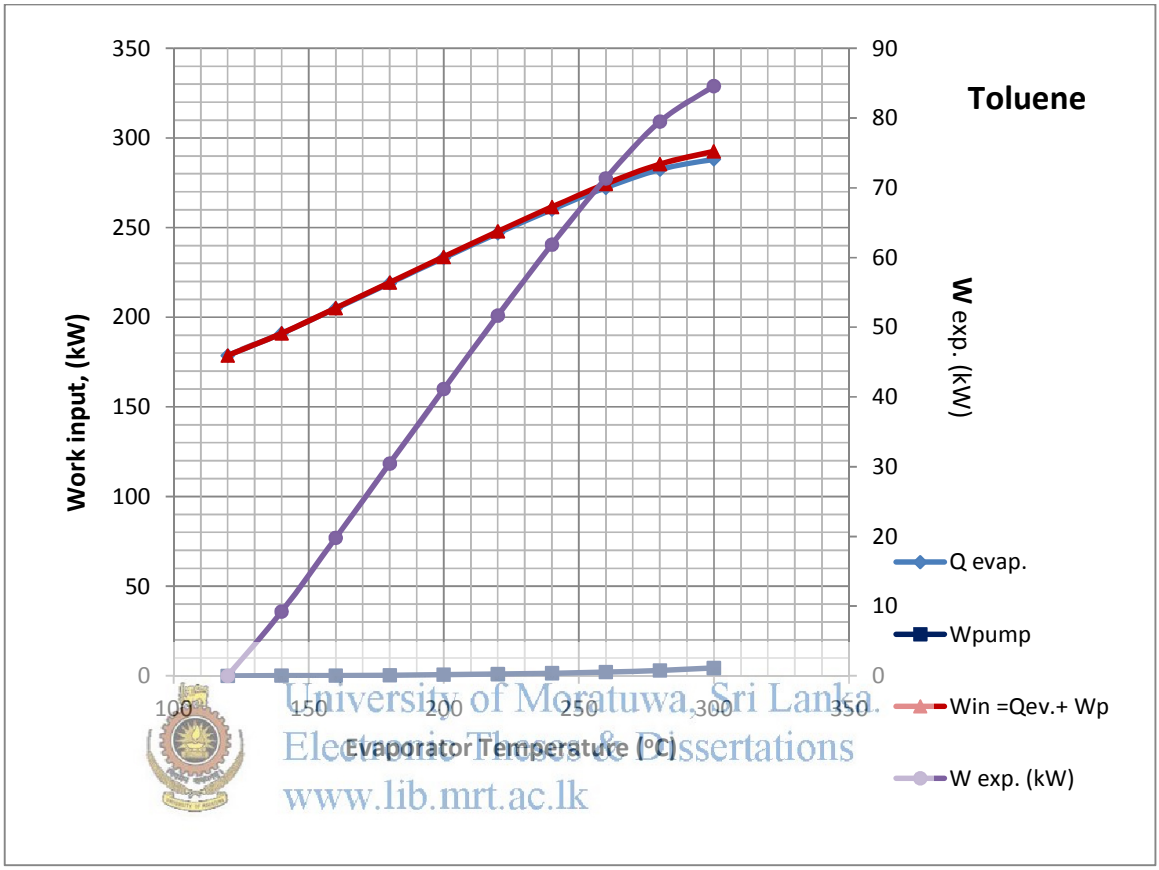


Graph B.5: Work Input and Efficiency variation with different Evaporator temperatures for R123

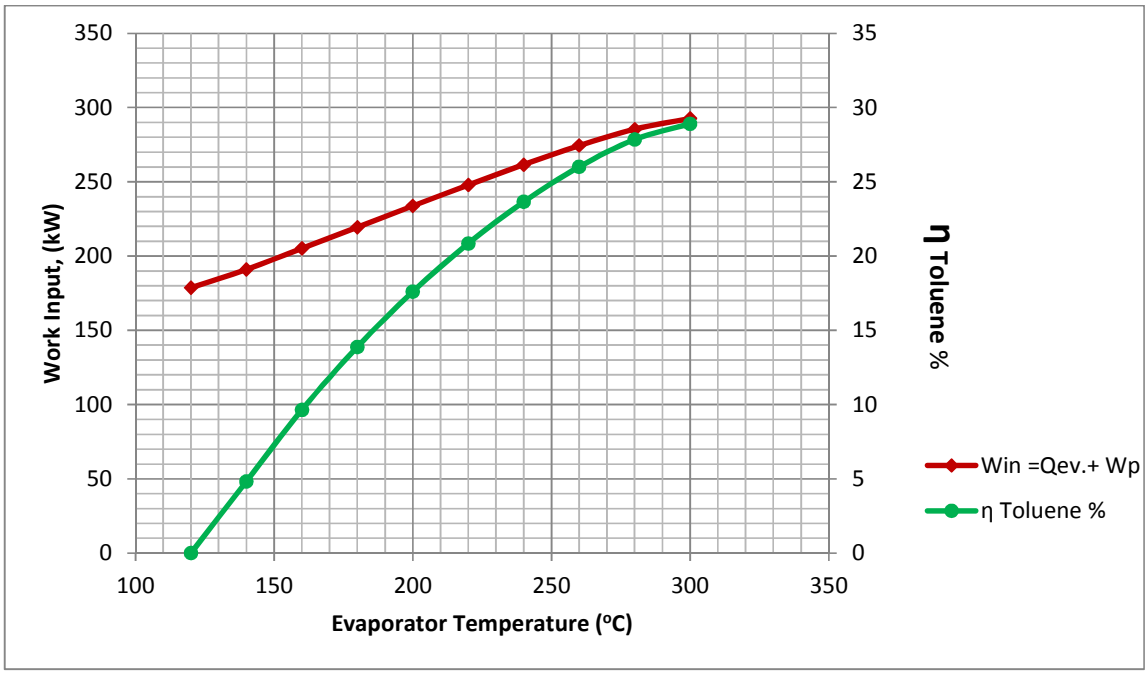


Graph B.6: Work Input and Work at Expander variation with different Evaporator temperatures for R123

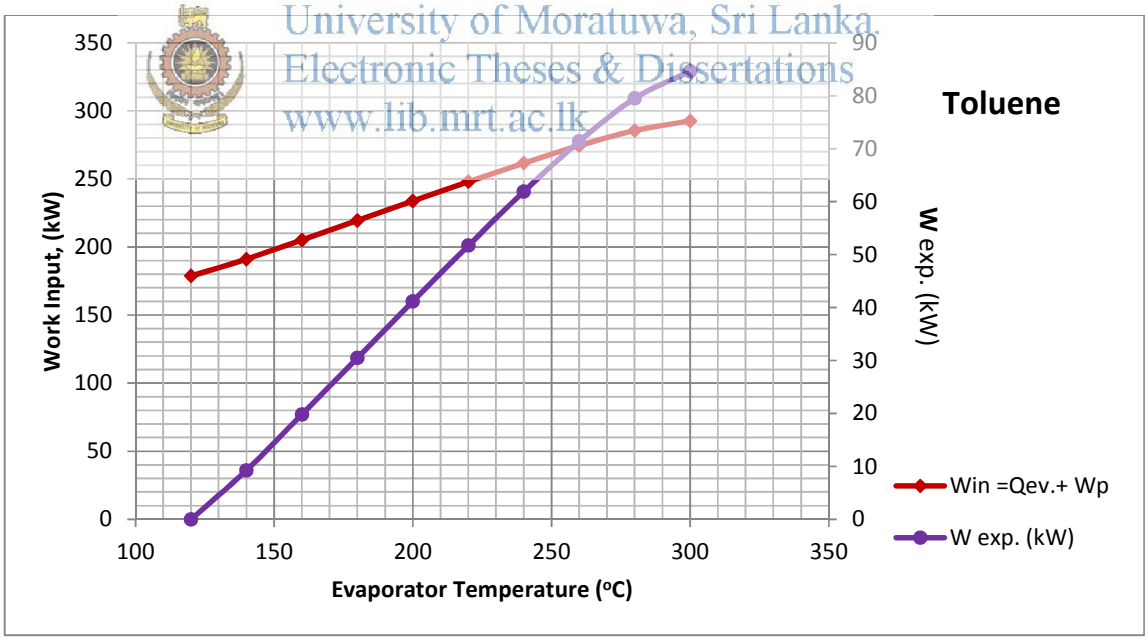
Toluene as working fluid



Graph B.7: Variation of Work component in the cycle with different Evaporator temperatures for Toluene

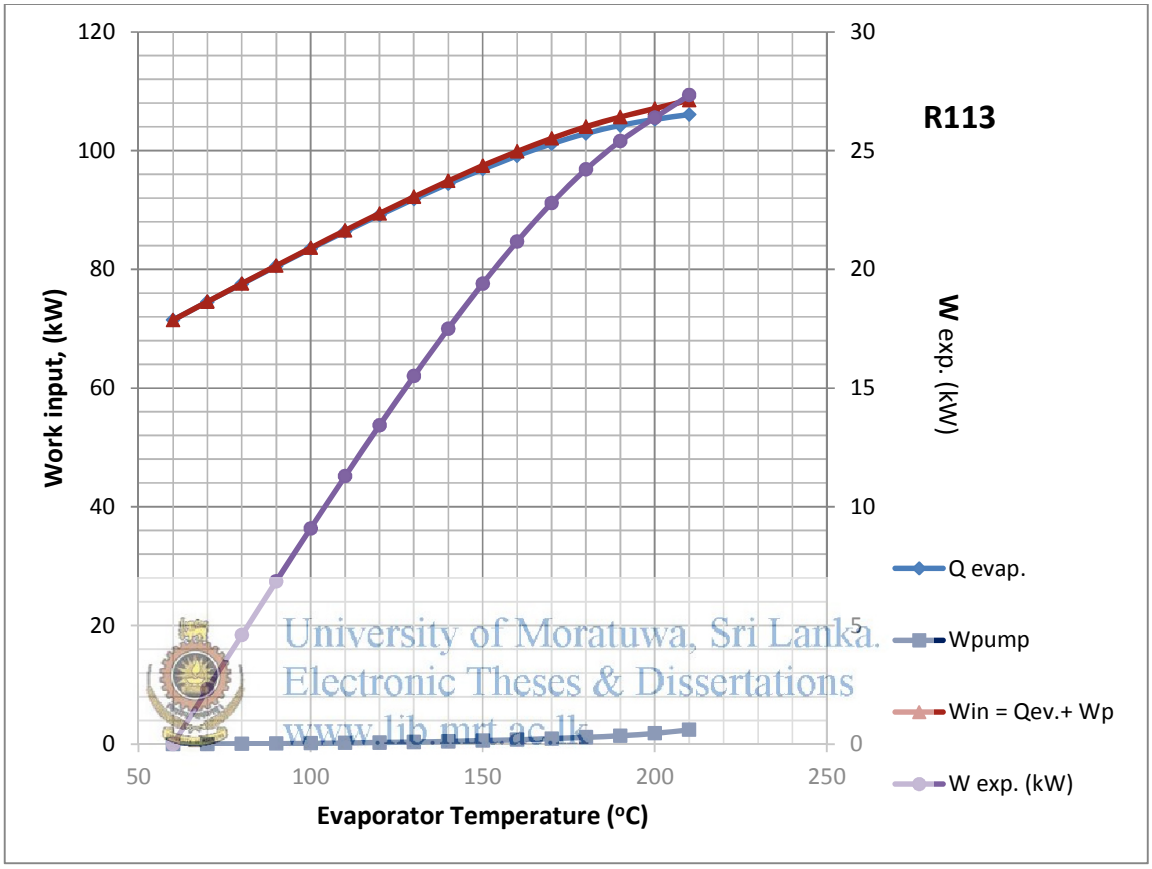


Graph B.8: Work Input and Efficiency variation with different Evaporator temperatures for Toluene

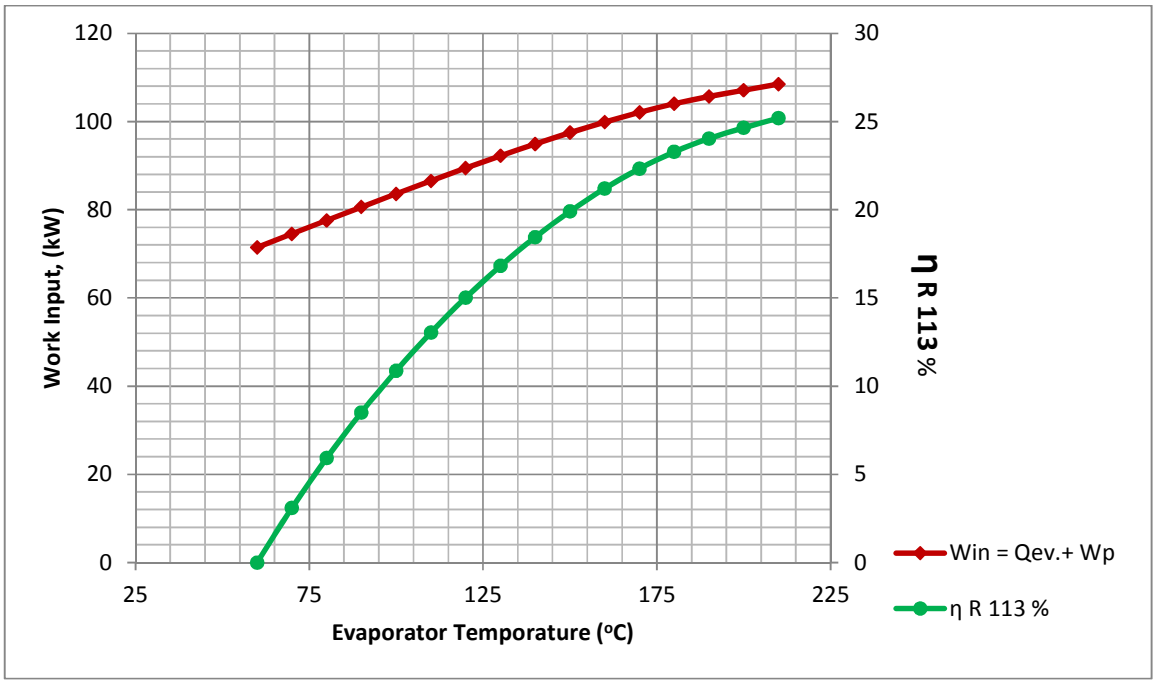


Graph B.9: Work Input and Work at Expander variation with different Evaporator temperatures for Toluene

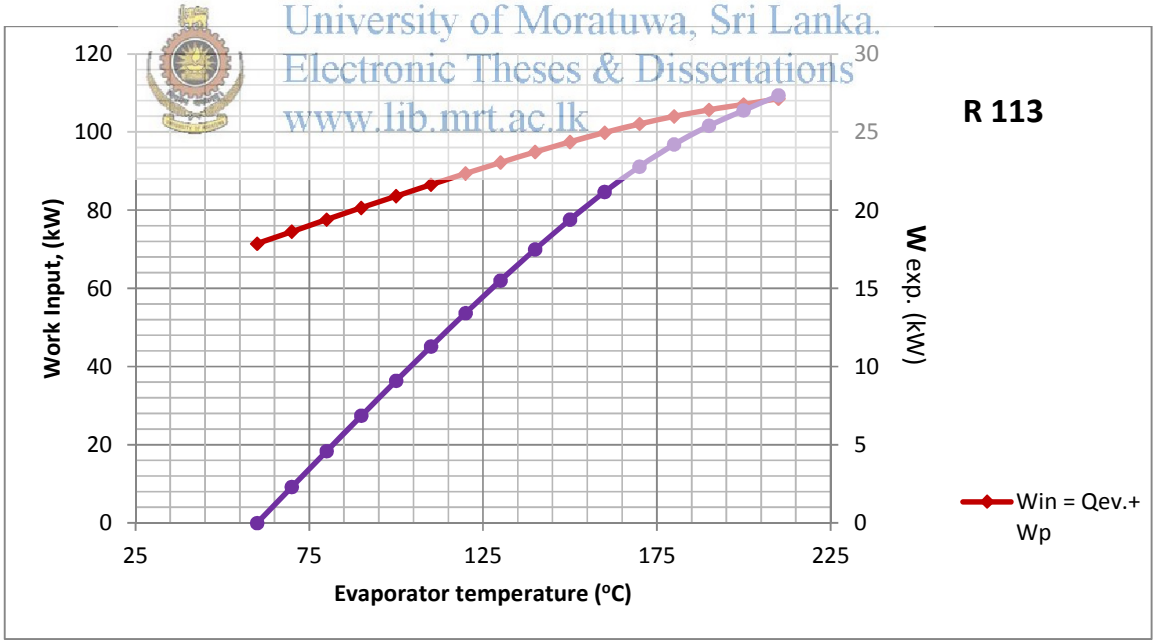
R113 refrigerant as working fluid



Graph B.10: Variation of Work component in the cycle with different Evaporator temperatures for R113

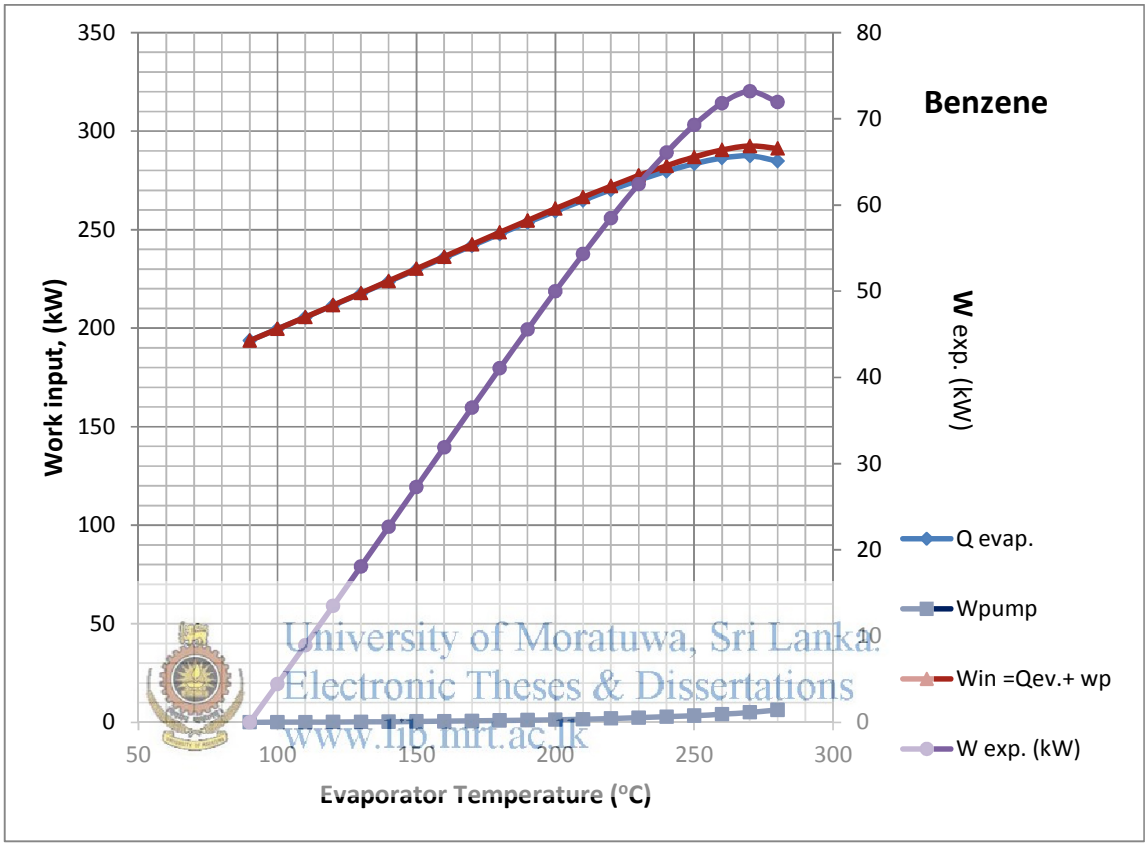


Graph B.11: Work Input and Efficiency variation with different Evaporator temperatures for R113

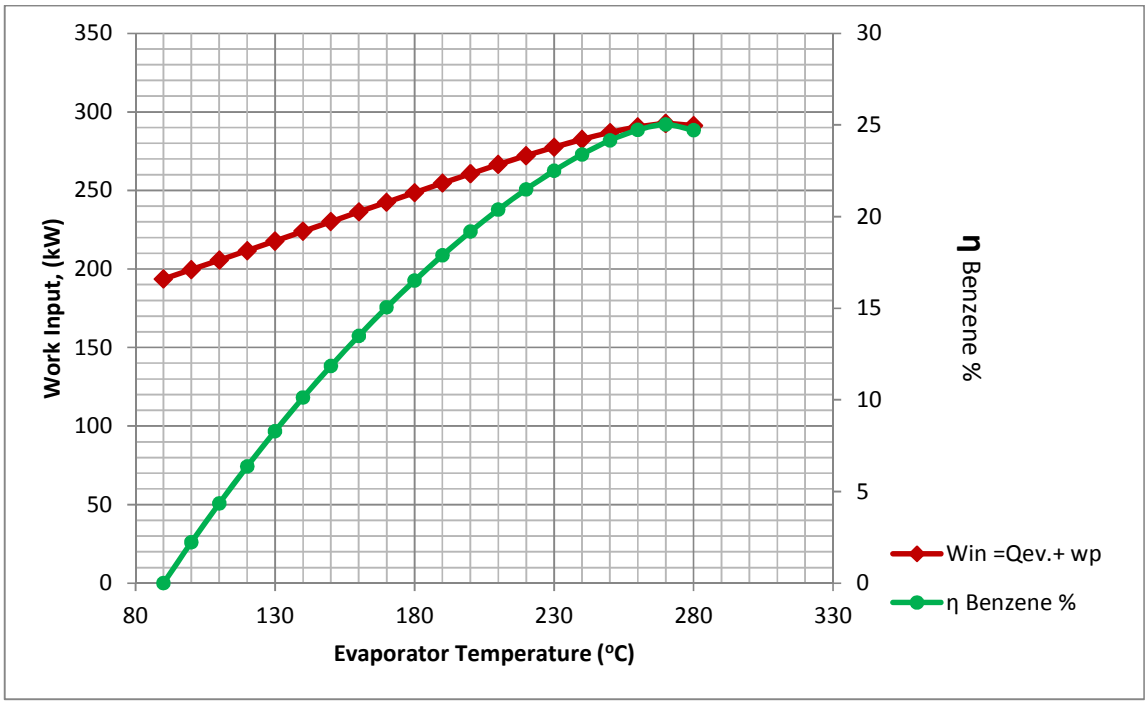


Graph B.12: Work Input and Work at Expander variation with different Evaporator temperatures for R113

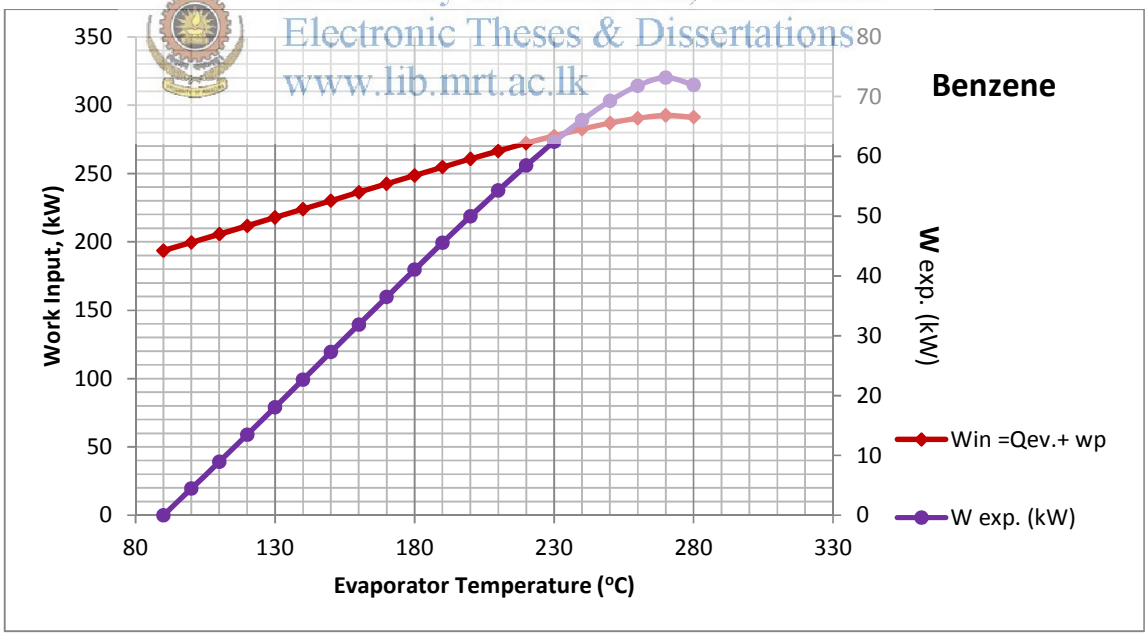
Benzene as working fluid



Graph B.13: Variation of Work component in the cycle with different Evaporator temperatures for Benzene

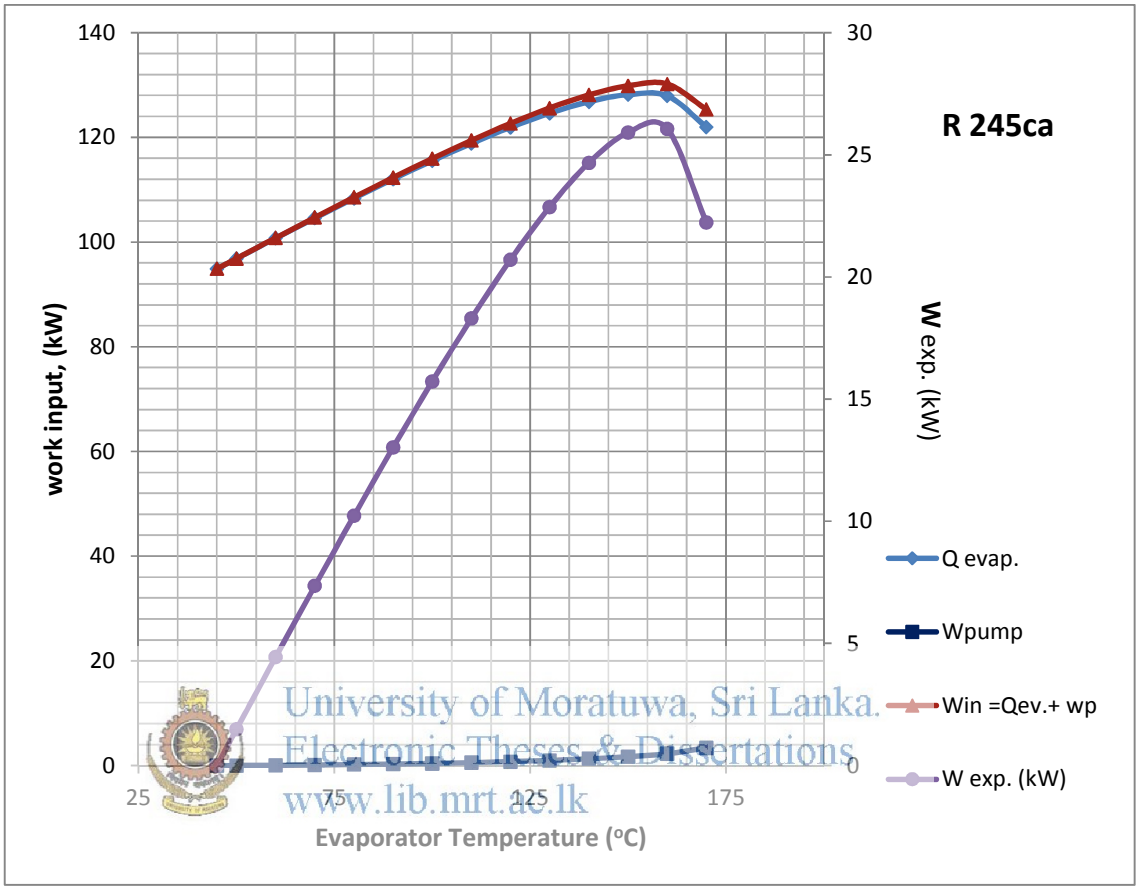


Graph B.14: Work Input and Efficiency variation with different Evaporator temperatures for Benzene

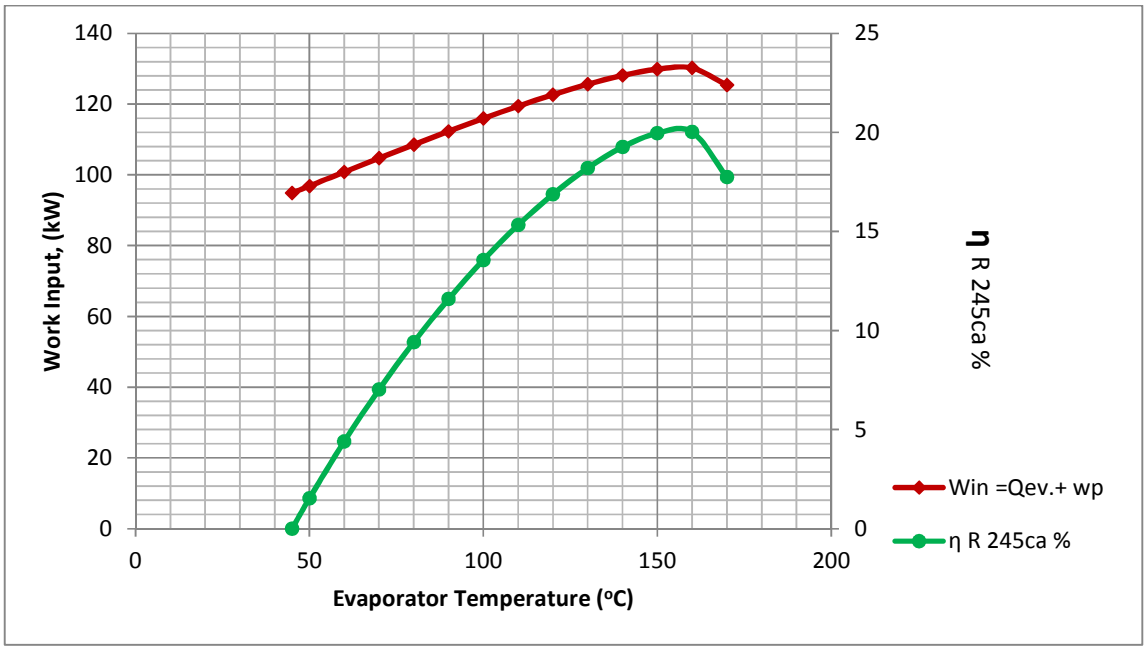


Graph B.15: Work Input and Work at Expander variation with different Evaporator temperatures for Benzene

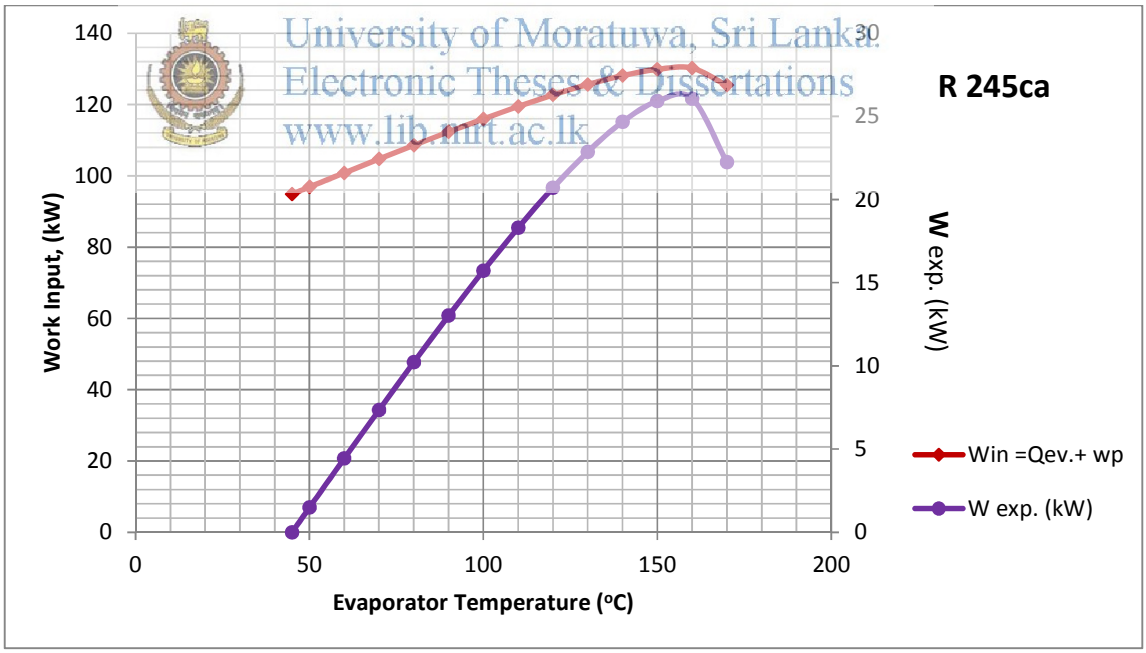
R245ca as working fluid



Graph B.16: Variation of Work component in the cycle with different Evaporator temperatures for R245ca

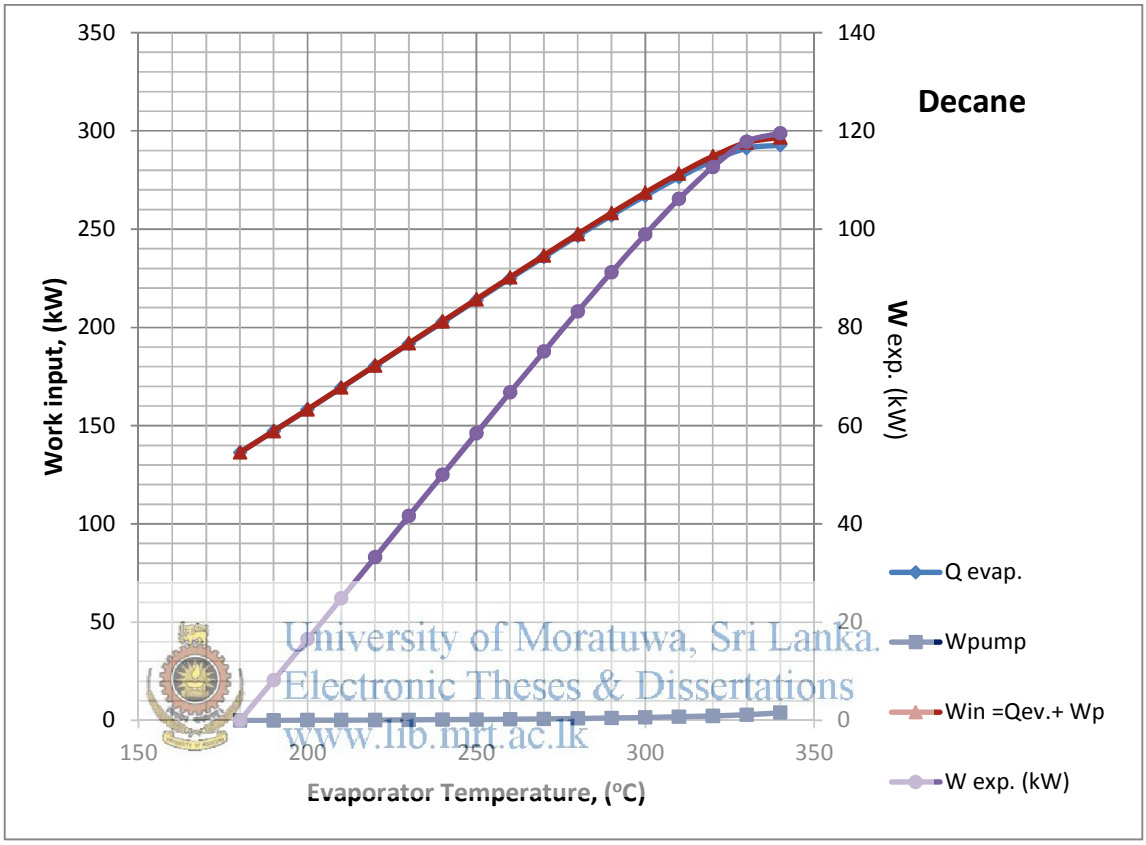


Graph B.17: Work Input and Efficiency variation with different Evaporator temperatures for R245ca

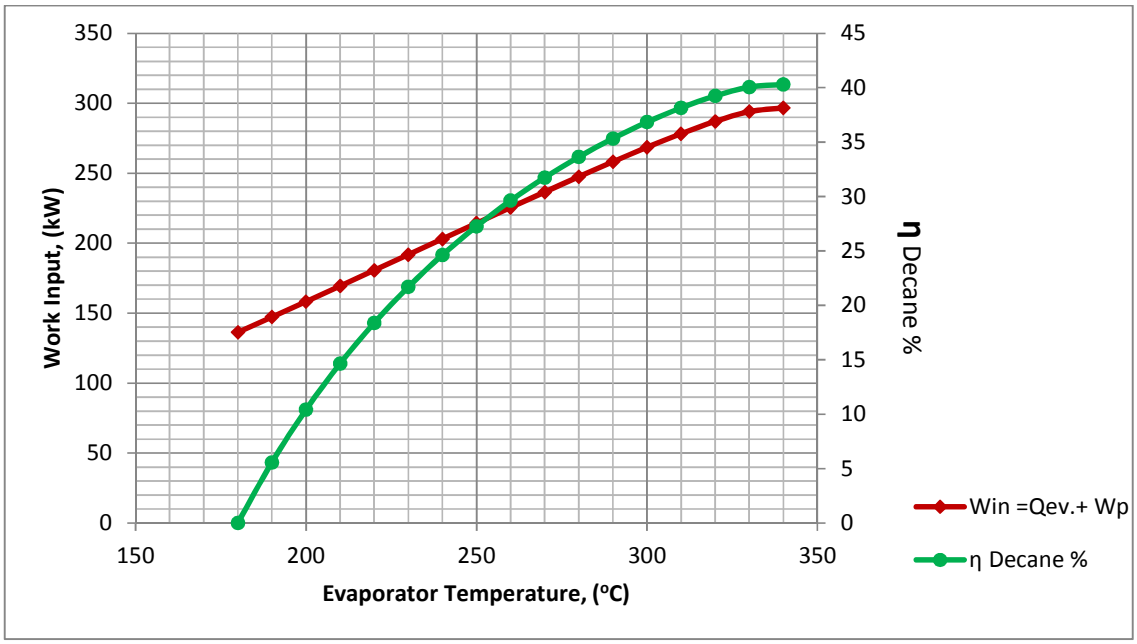


Graph B.18: Work Input and Work at Expander variation with different Evaporator temperatures for R245ca

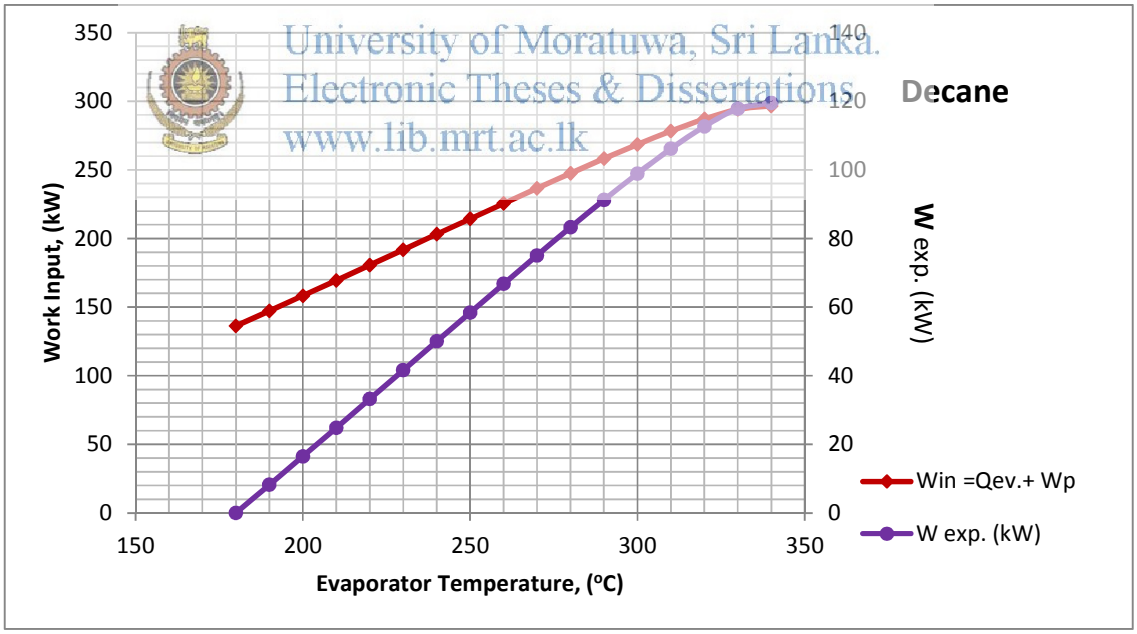
Decane as working fluid



Graph B.19: Variation of Work component in the cycle with different Evaporator temperatures for Decane

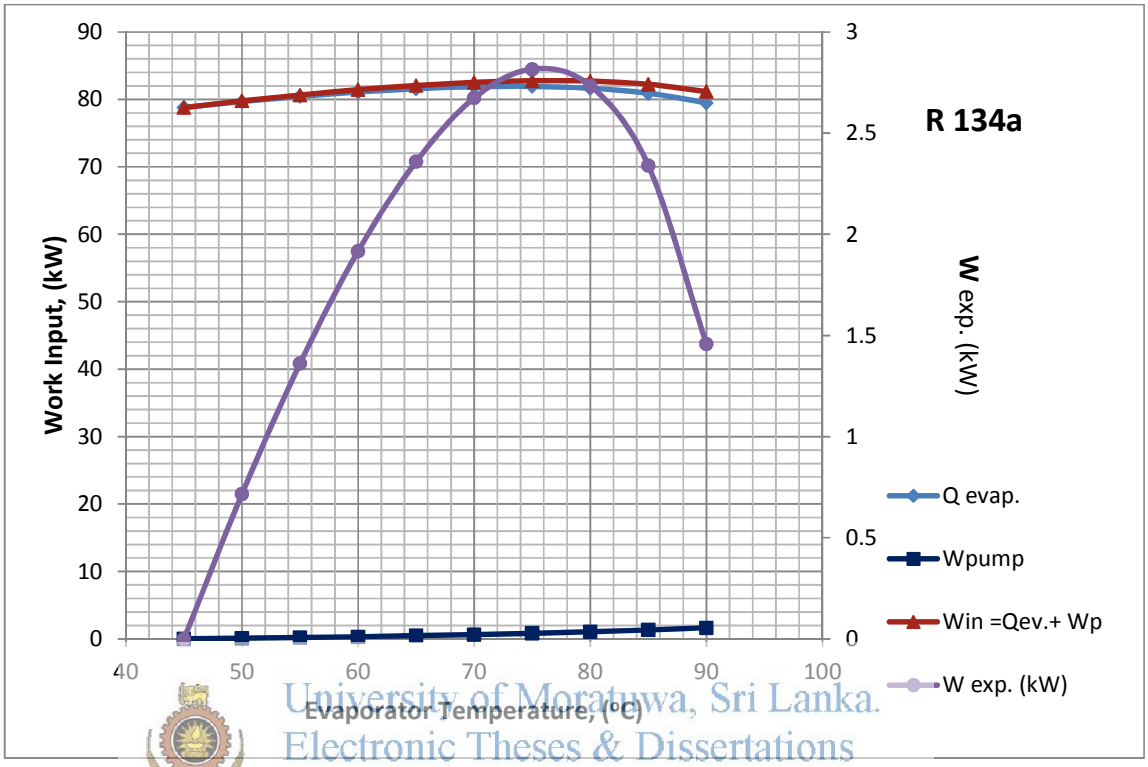


Graph B.20: Work Input and Efficiency variation with different Evaporator temperatures for Decane

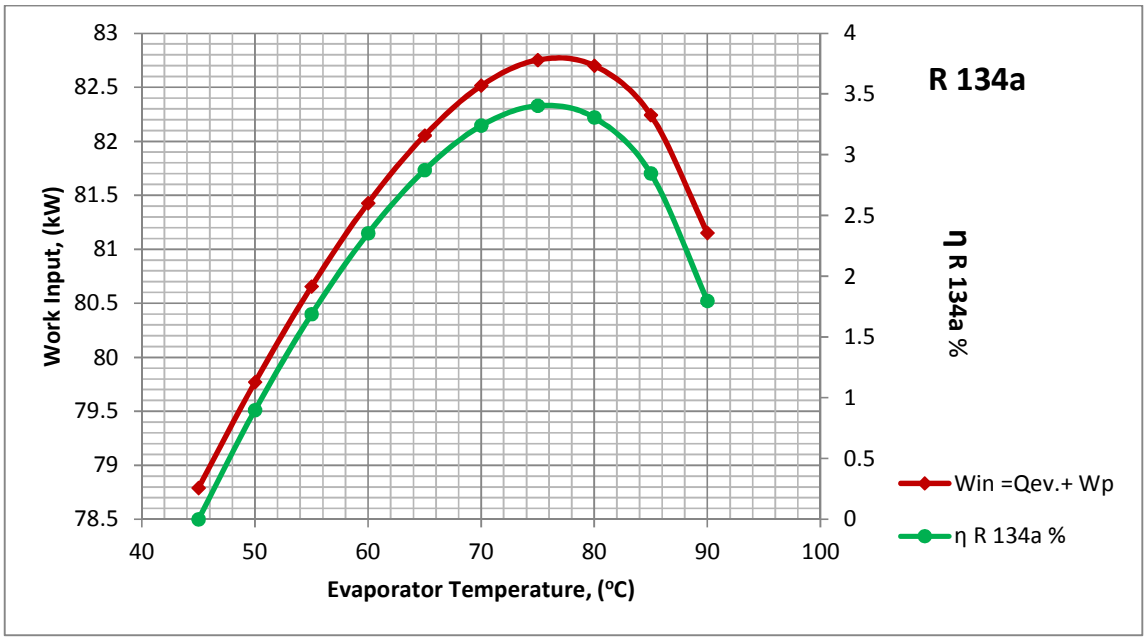


Graph B.21: Work Input and Work at Expander variation with different Evaporator temperatures for Decane

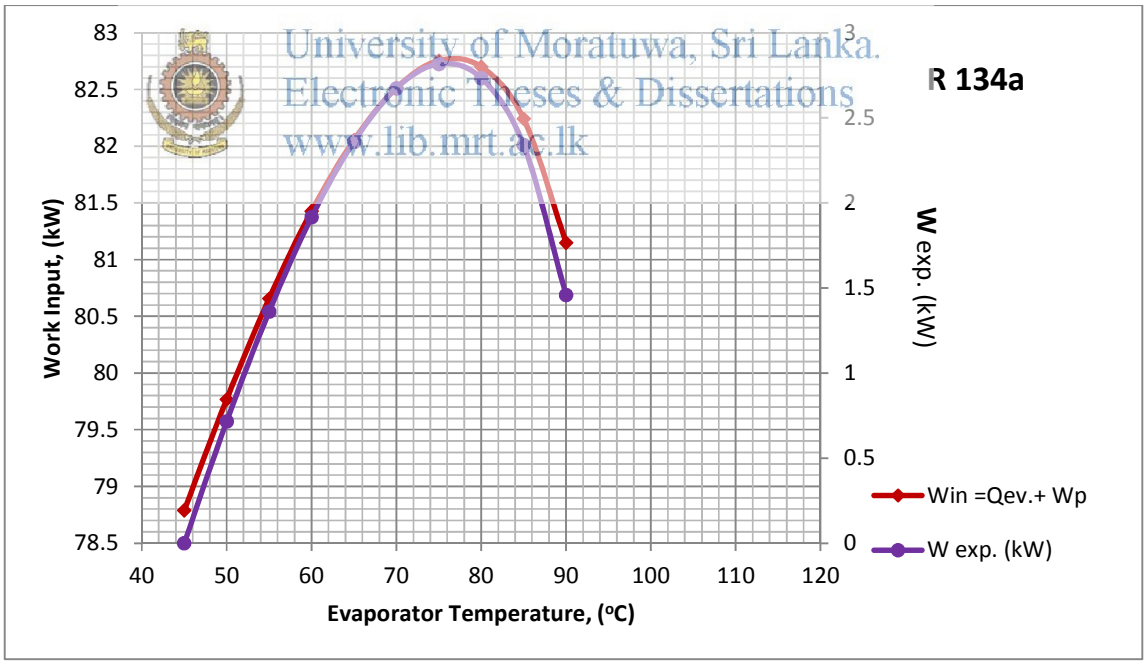
R134a as working fluid



Graph B.22: Variation of Work component in the cycle with different Evaporator temperatures for R134a

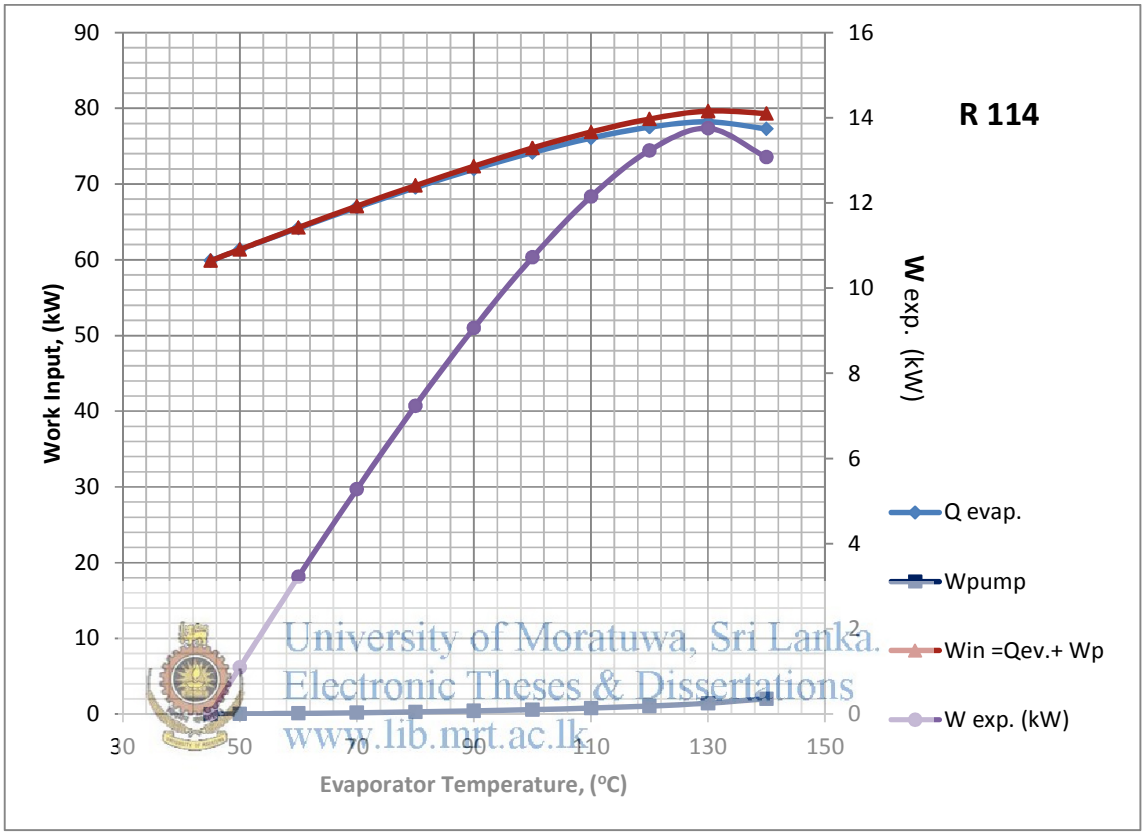


Graph B.23: Work Input and Efficiency variation with different Evaporator temperatures for R134a

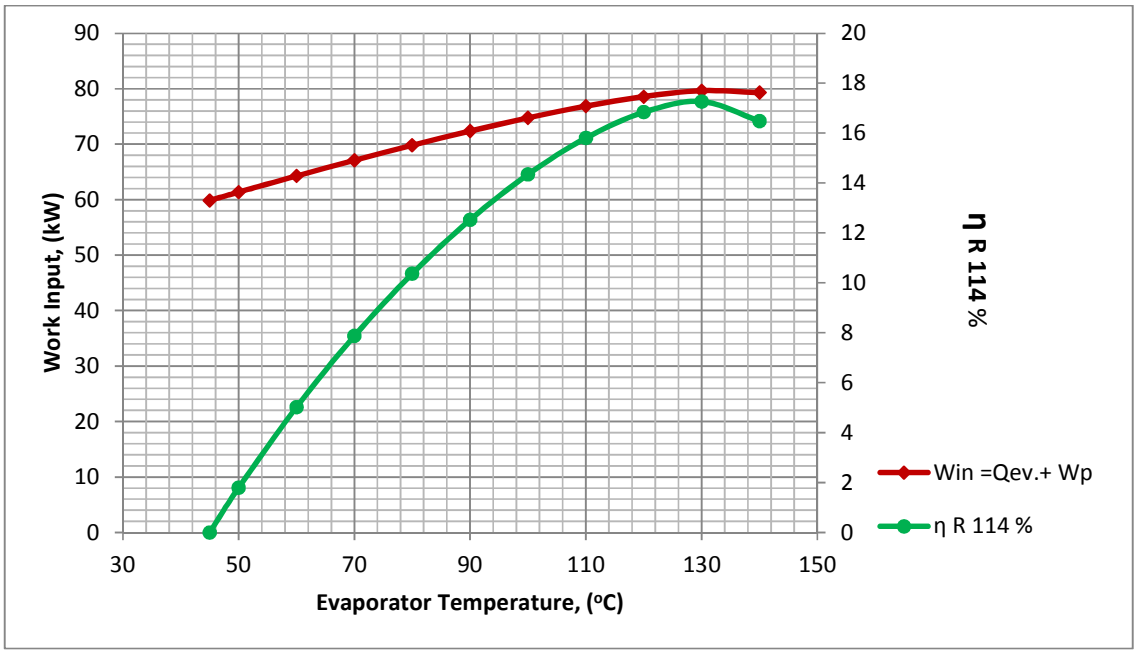


Graph B.24: Work Input and Work at Expander variation with different Evaporator temperatures for R134a

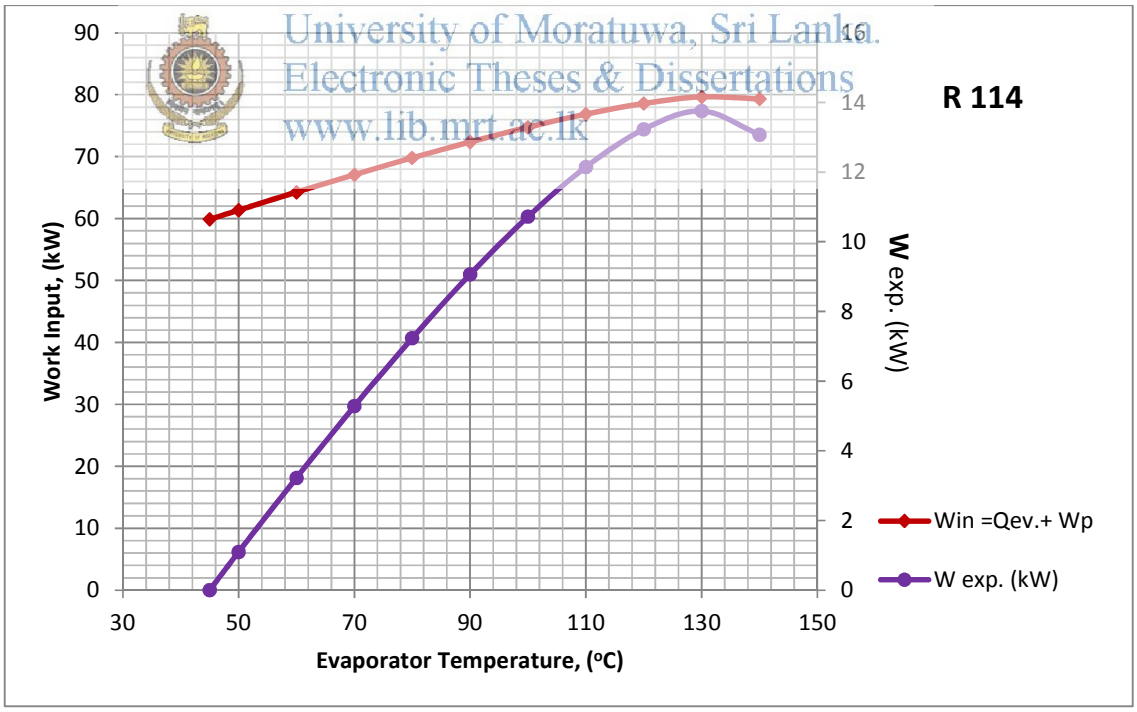
R114 as working fluid



Graph B.25: Variation of Work component in the cycle with different Evaporator temperatures for R114

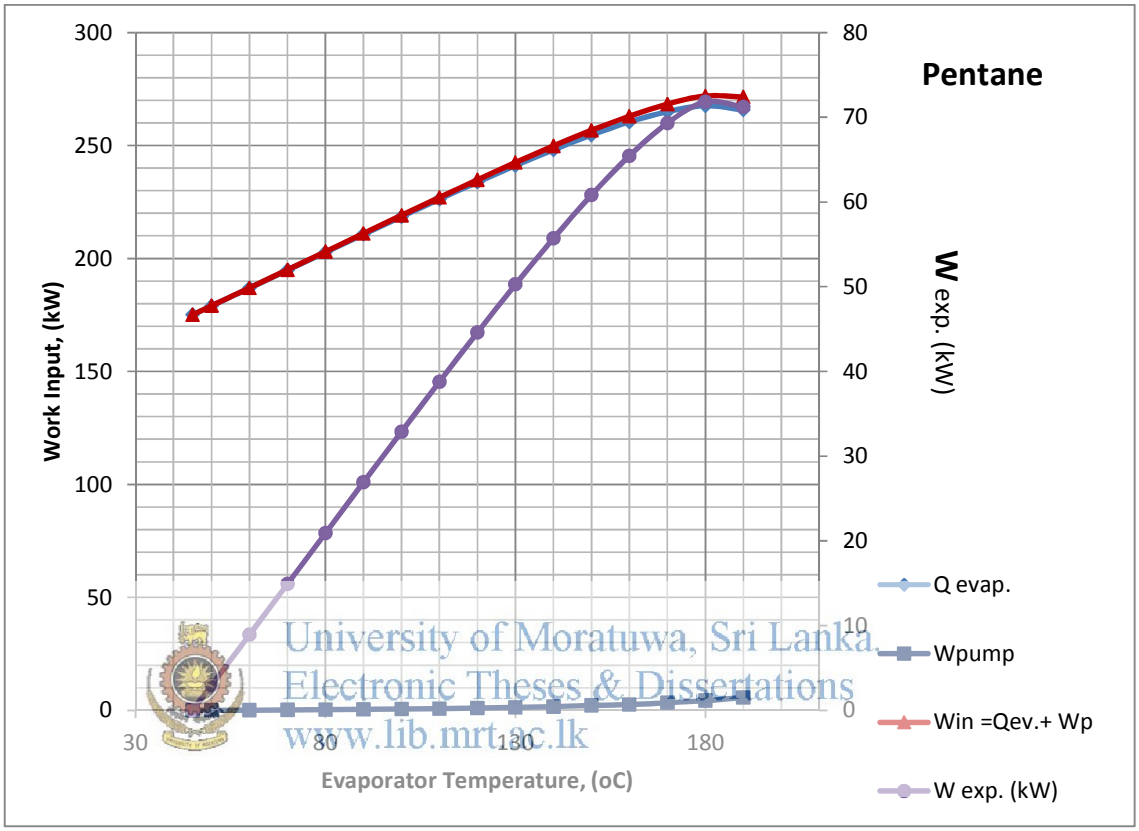


Graph B.26: Work Input and Efficiency variation with different Evaporator temperatures for R114

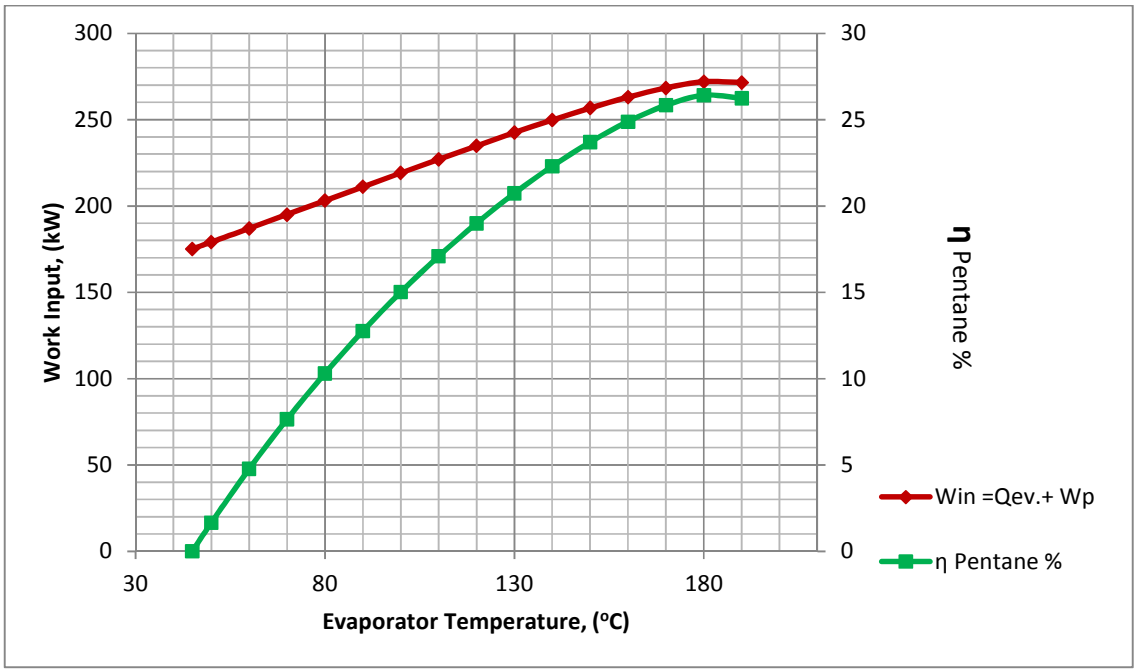


Graph B.27: Work Input and Work at Expander variation with different Evaporator temperatures for R114

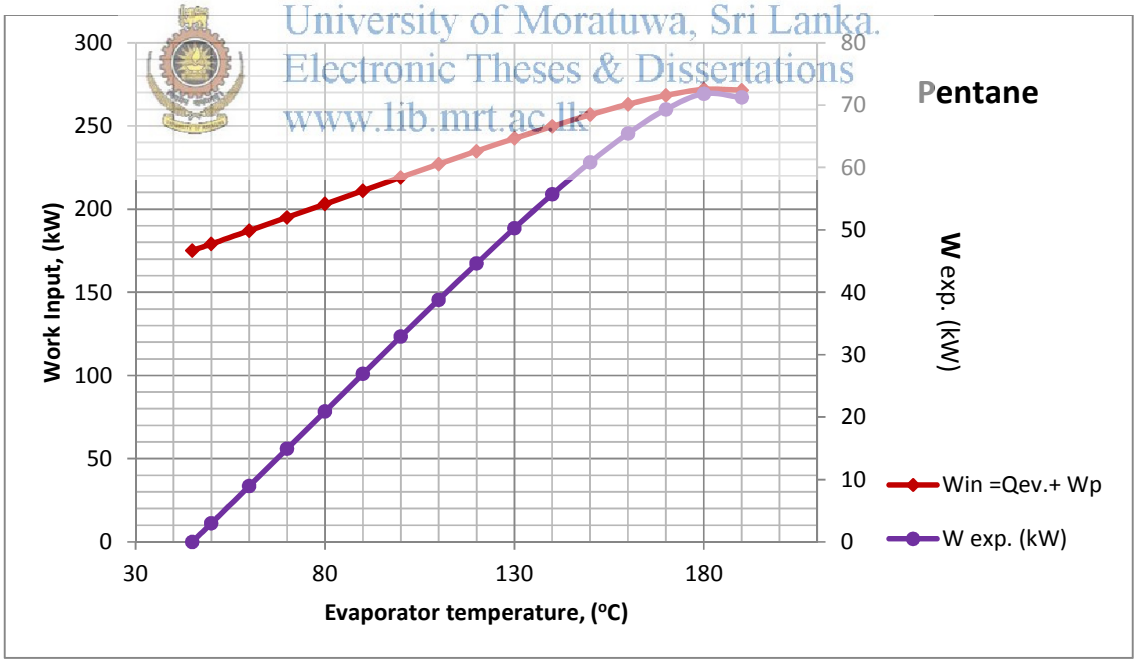
Pentane as working fluid



Graph B.28: Variation of Work component in the cycle with different Evaporator temperatures for Pentane

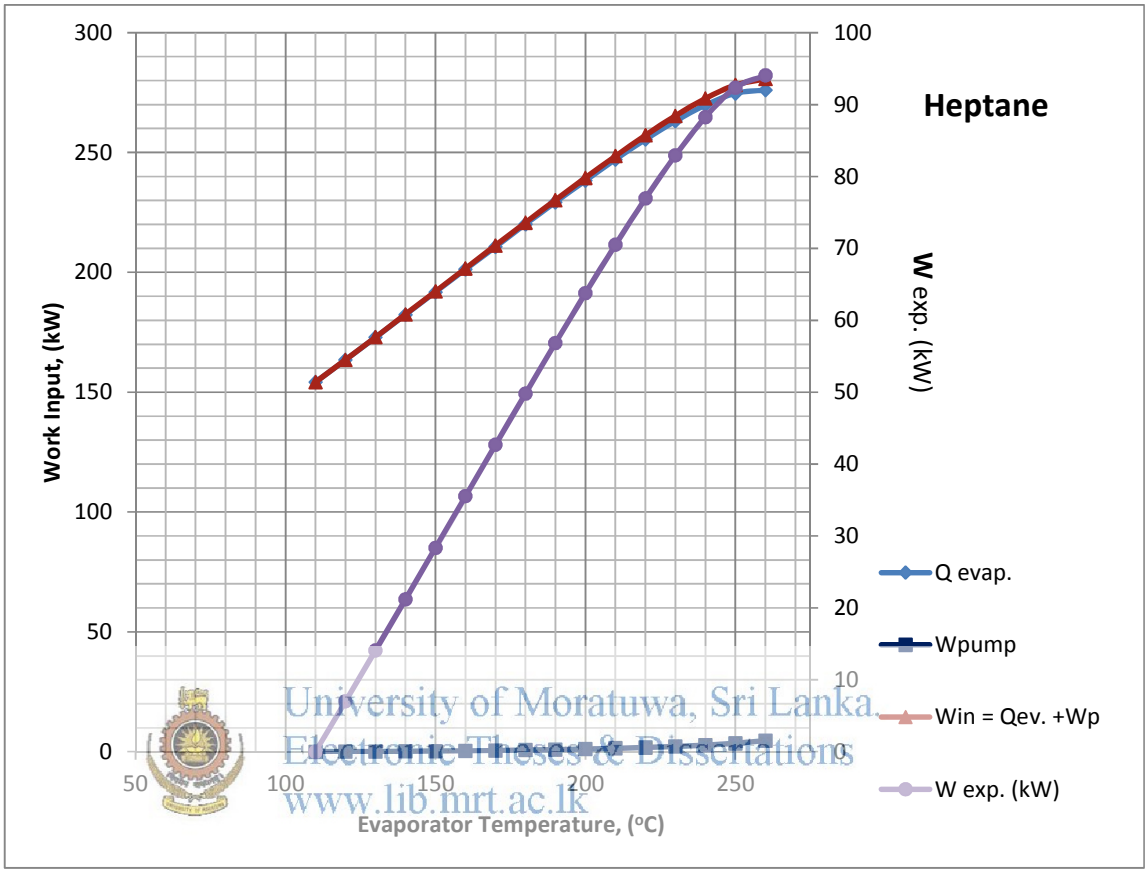


Graph B.29: Work Input and Efficiency variation with different Evaporator temperatures for Pentane

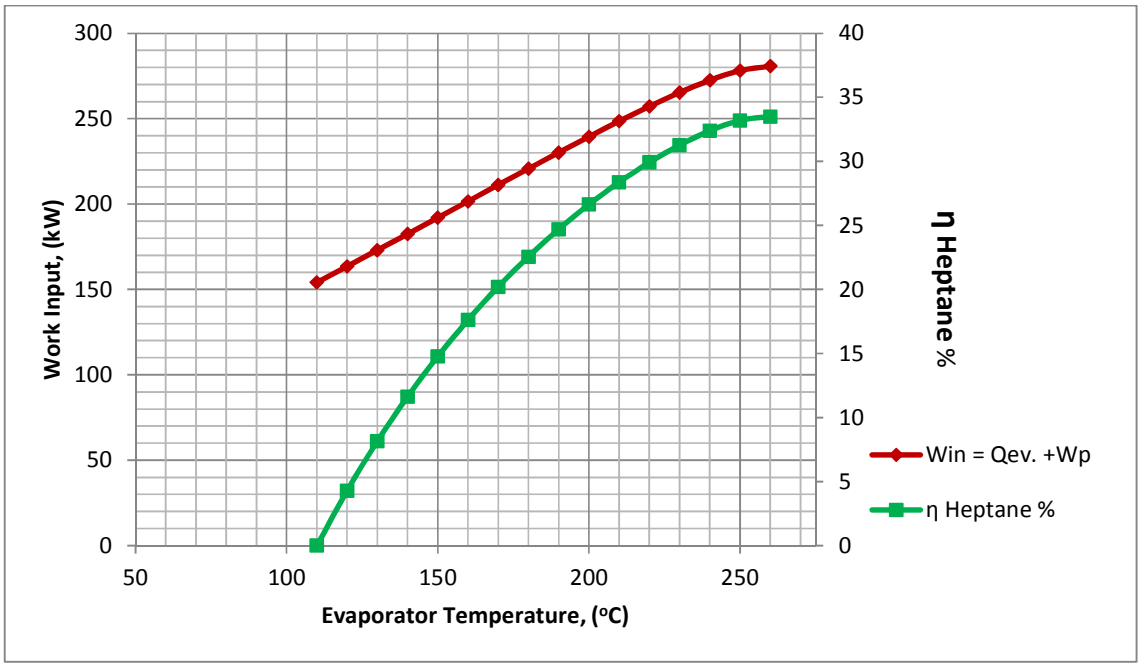


Graph B.30: Work Input and Work at Expander variation with different Evaporator temperatures for Pentane

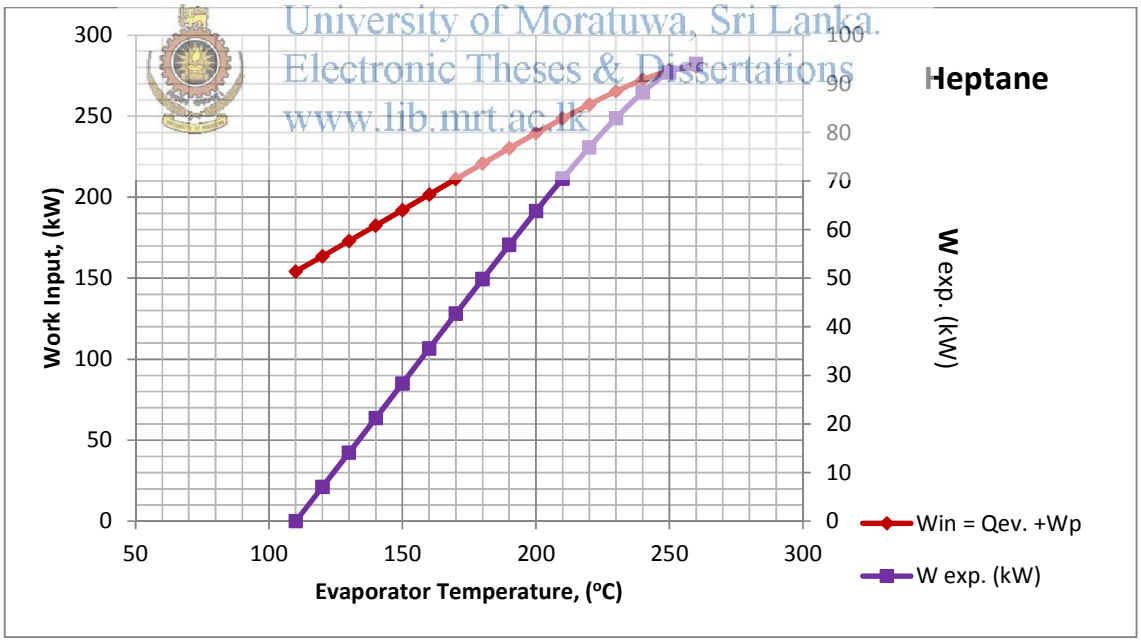
Heptane as working fluid



Graph B.31: Variation of Work component in the cycle with different Evaporator temperatures for Heptane



Graph B.32: Work Input and Efficiency variation with different Evaporator temperatures for Heptane

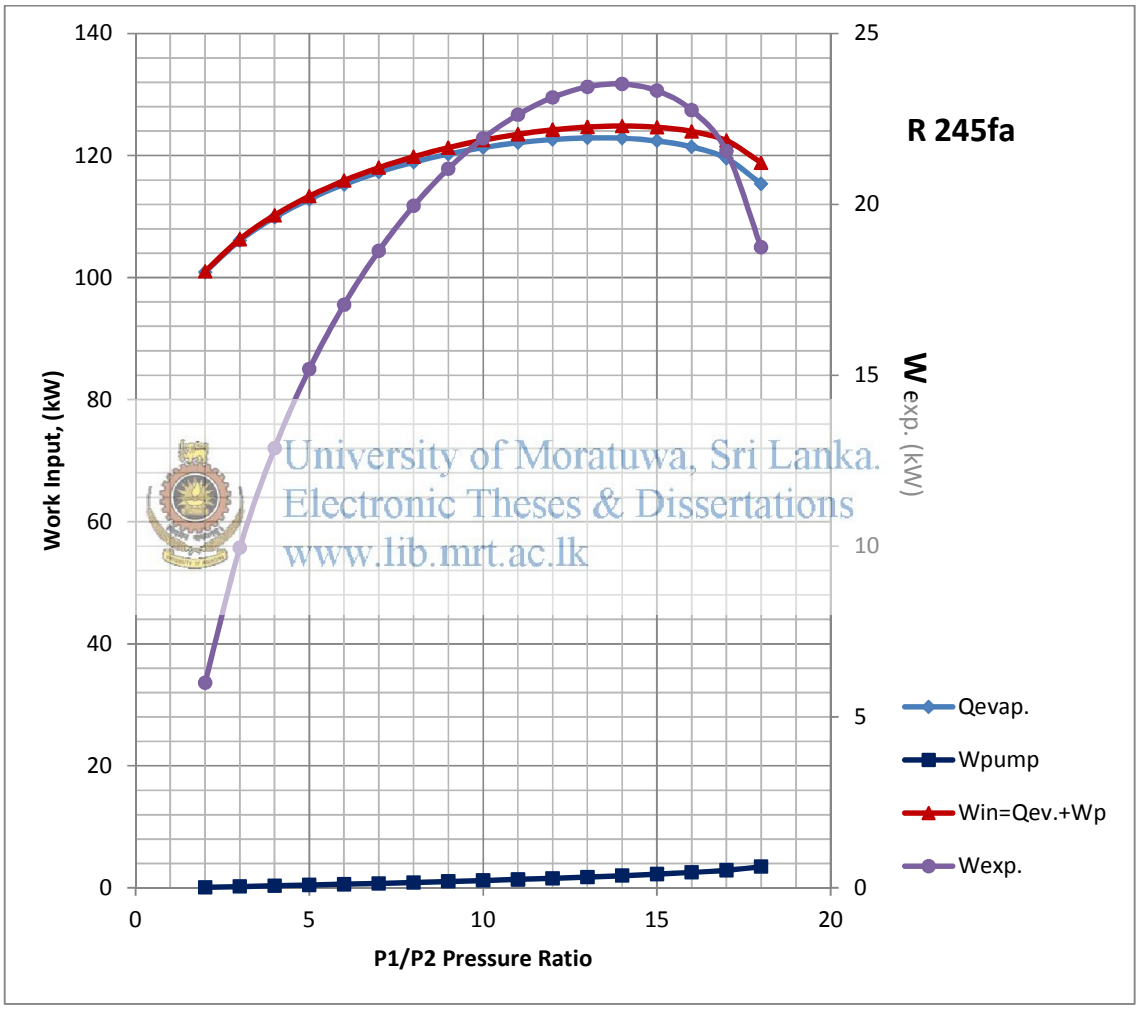


Graph B.33: Work Input and Work at Expander variation with different Evaporator temperatures for Heptane

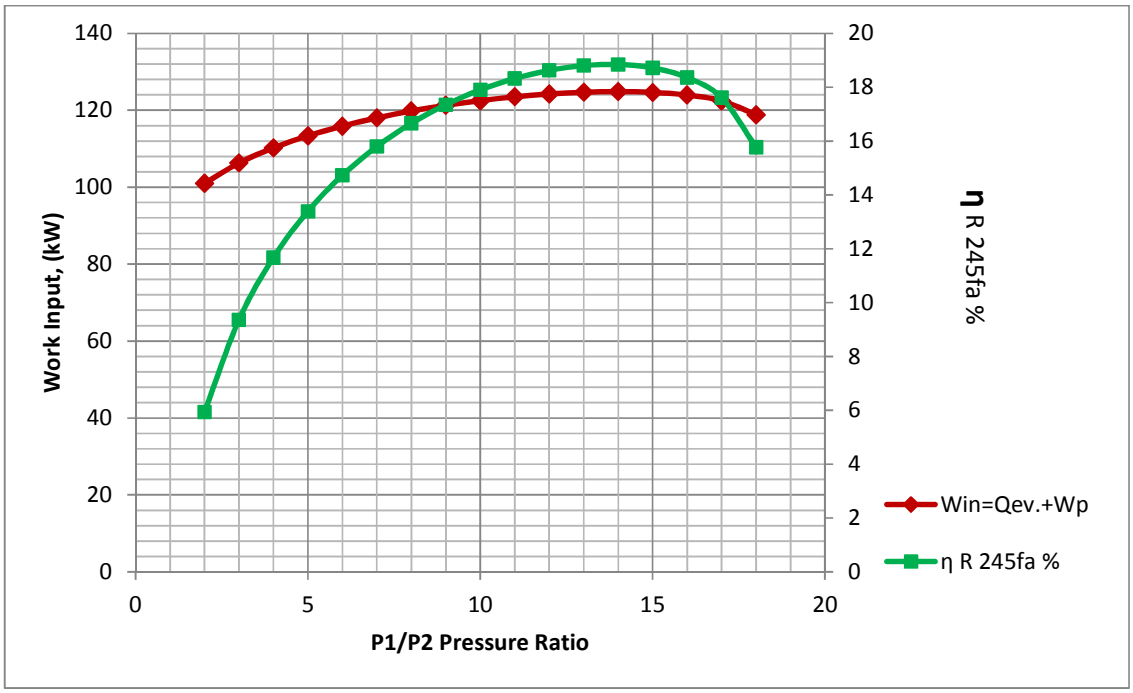
APPENDIX C

ORC PERFORMANCE ANALYSIS WITH EXPANDER PRESSURE RATIO VARIATION

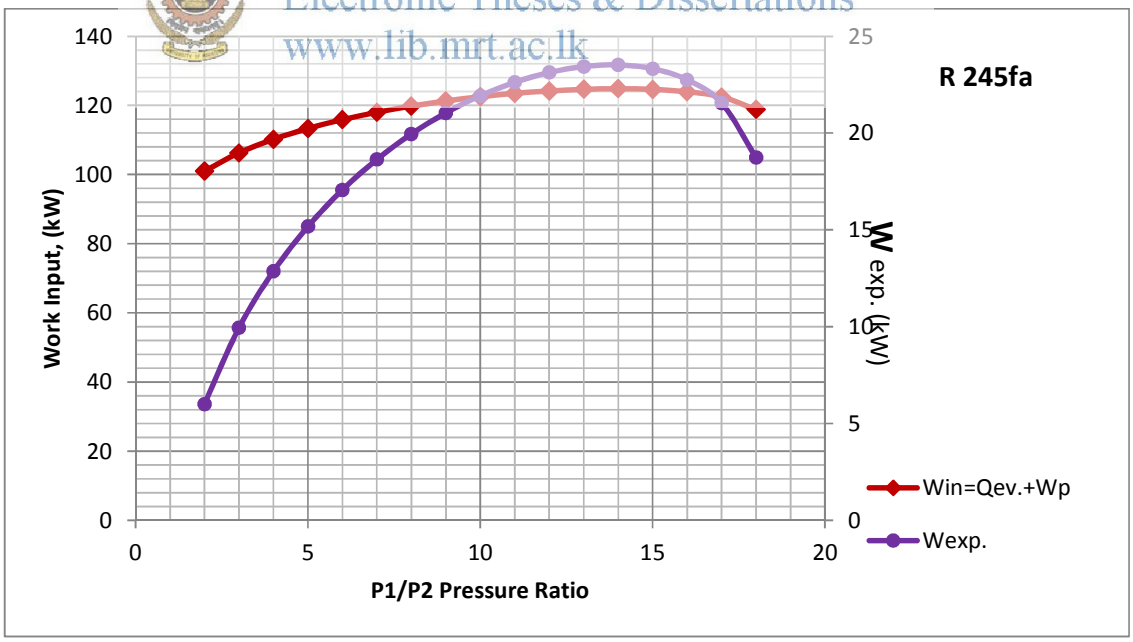
R245fa as working fluid



Graph C.34: Variation of Work component with different Expander pressure ratios for R245fa

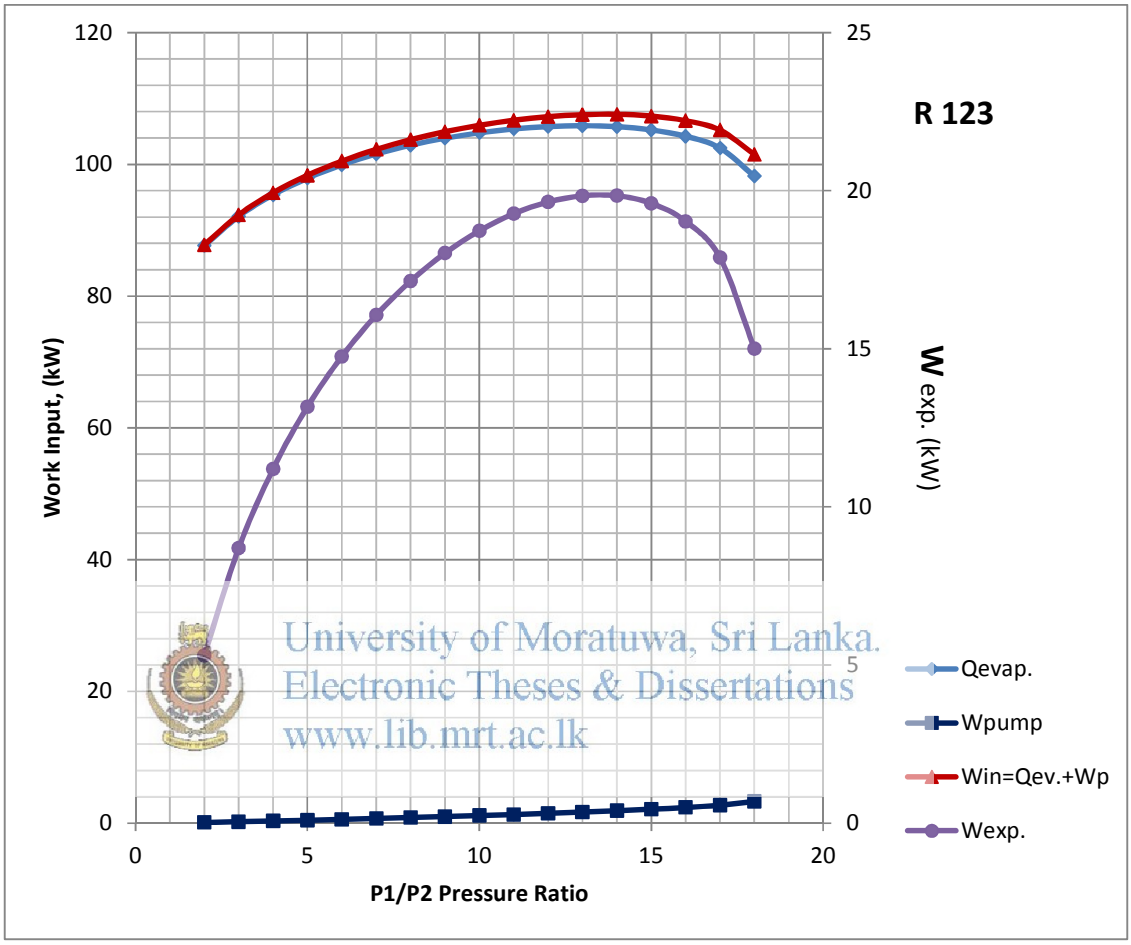


Graph C.35: Work Input and Efficiency variation with different Expander pressure ratios for R245fa

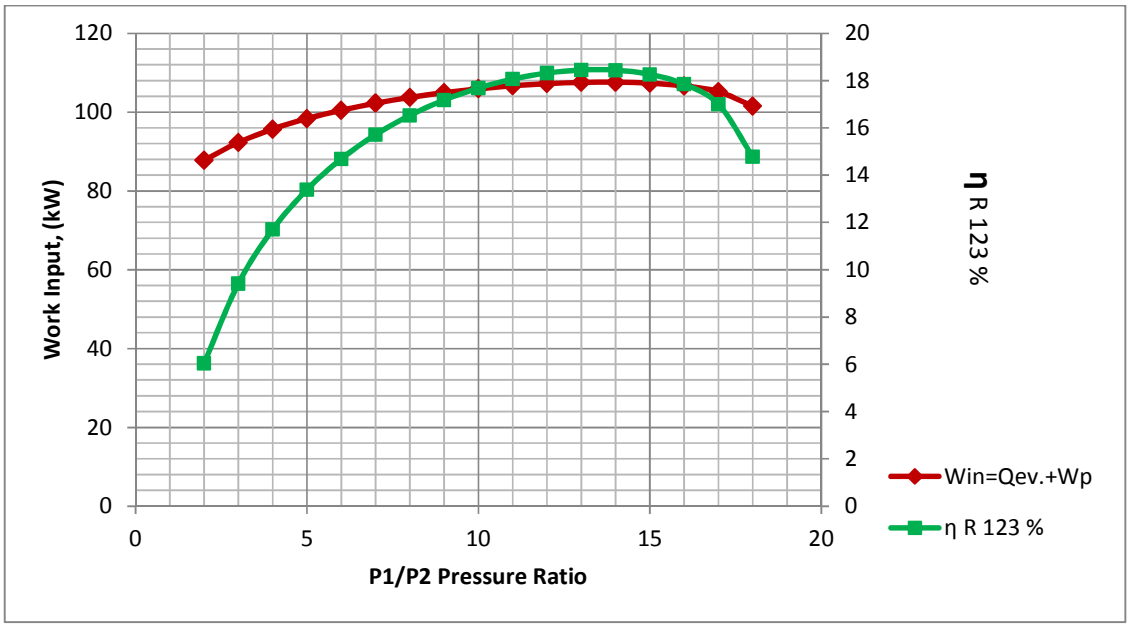


Graph C.36: Work Input and Work Output variation with different Expander pressure ratios for R245fa

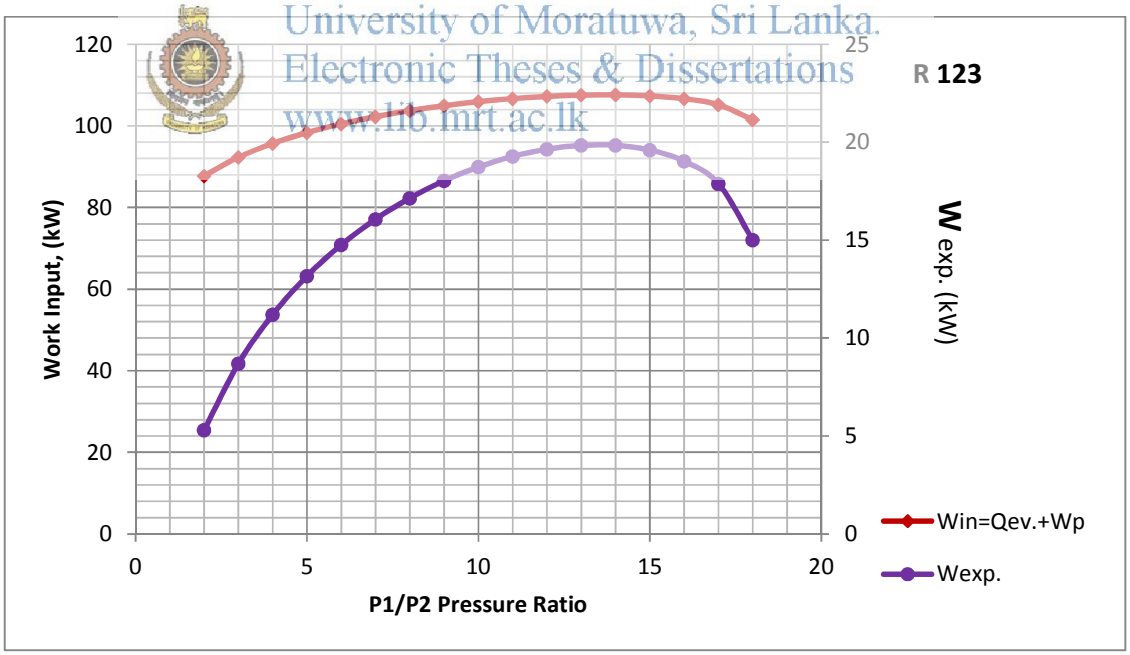
R123 as working fluid



Graph C.37: Variation of Work component with different Expander pressure ratios for R123

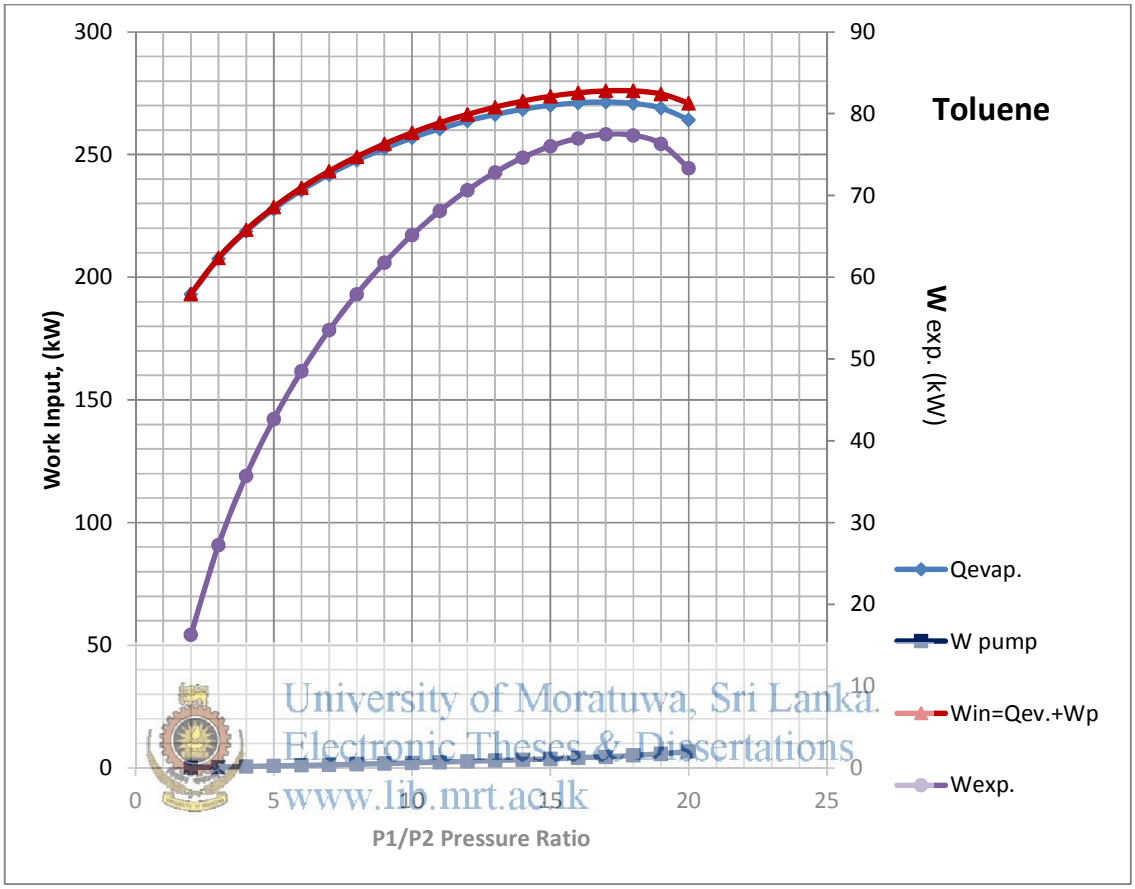


Graph C.38: Work Input and Efficiency variation with different Expander pressure ratios for R123

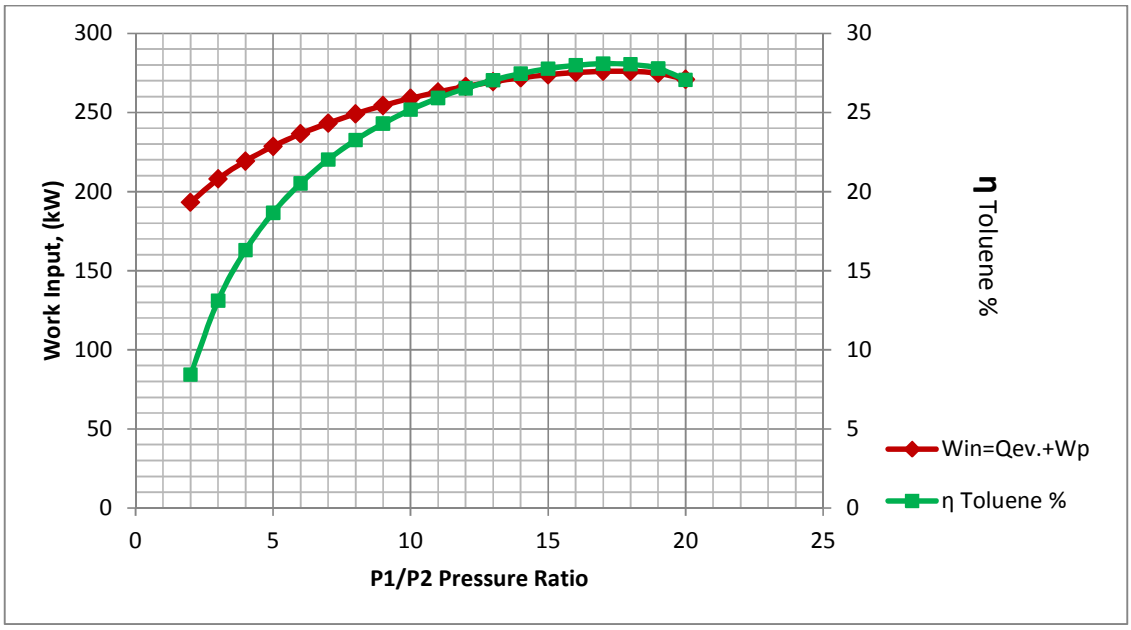


Graph C.39: Work Input and Work Output variation with different Expander pressure ratios for R123

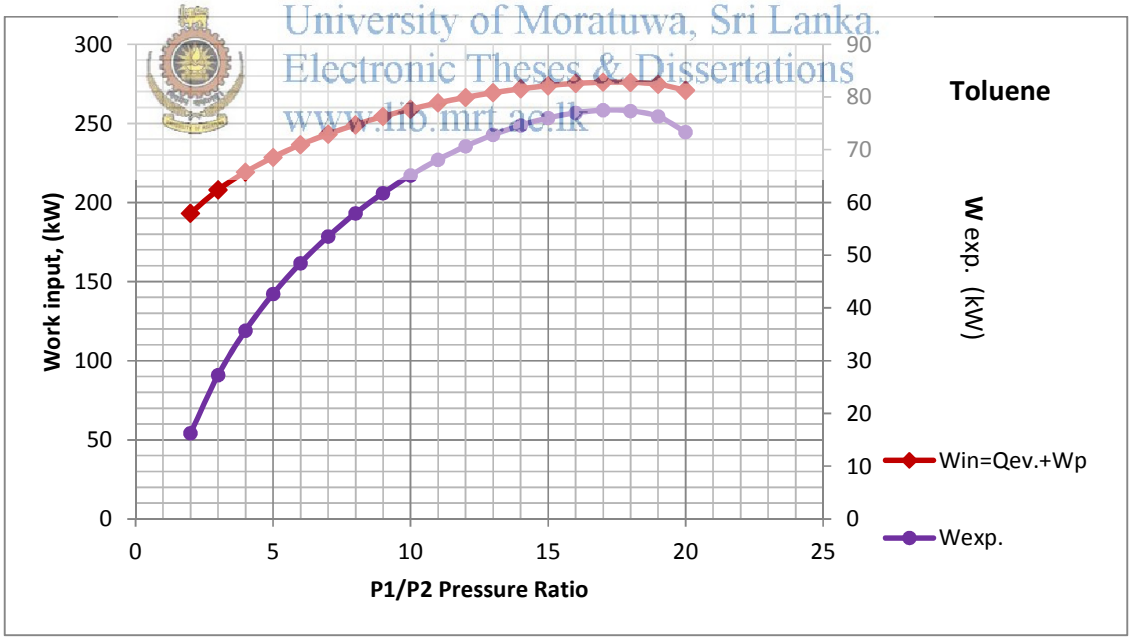
Toluene as working fluid



Graph C.40: Variation of Work component with different Expander pressure ratios for Toluene

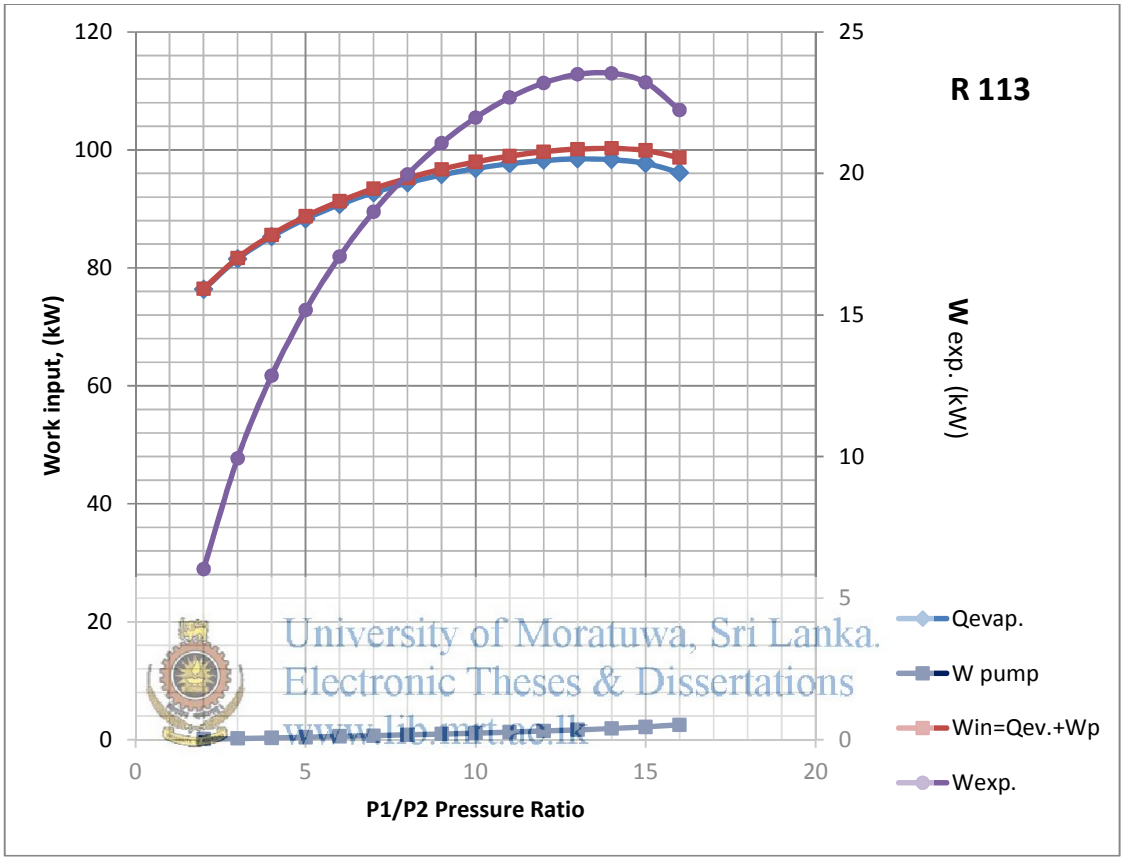


Graph C.41: Work Input and Efficiency variation with different Expander pressure ratios for Toluene

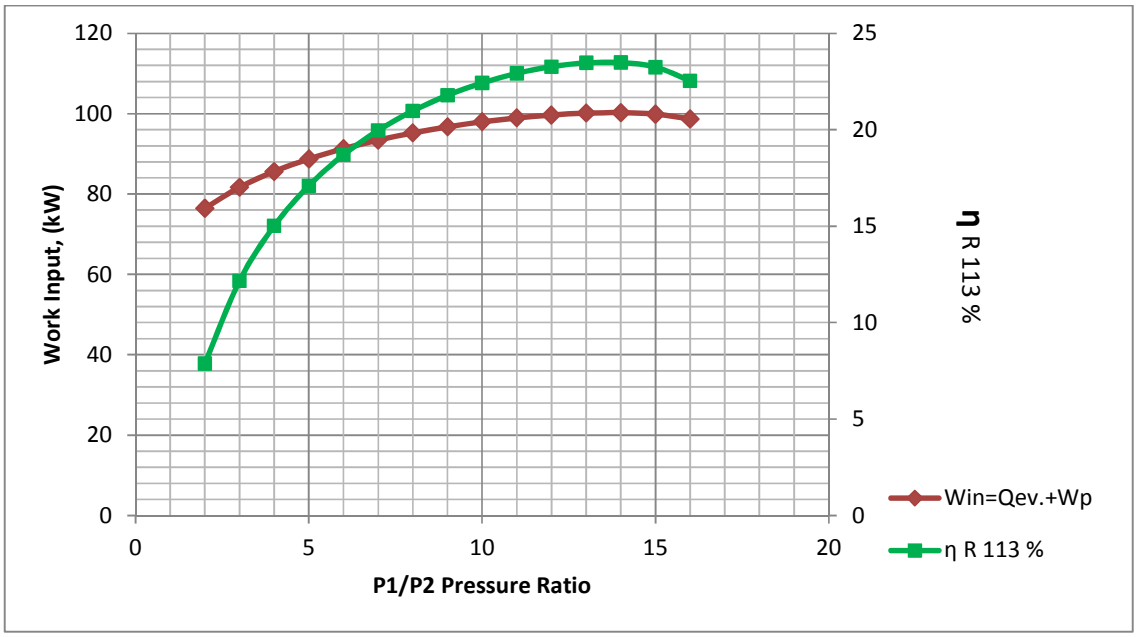


Graph C.42: Work Input and Work Output variation with different Expander pressure ratios for Toluene

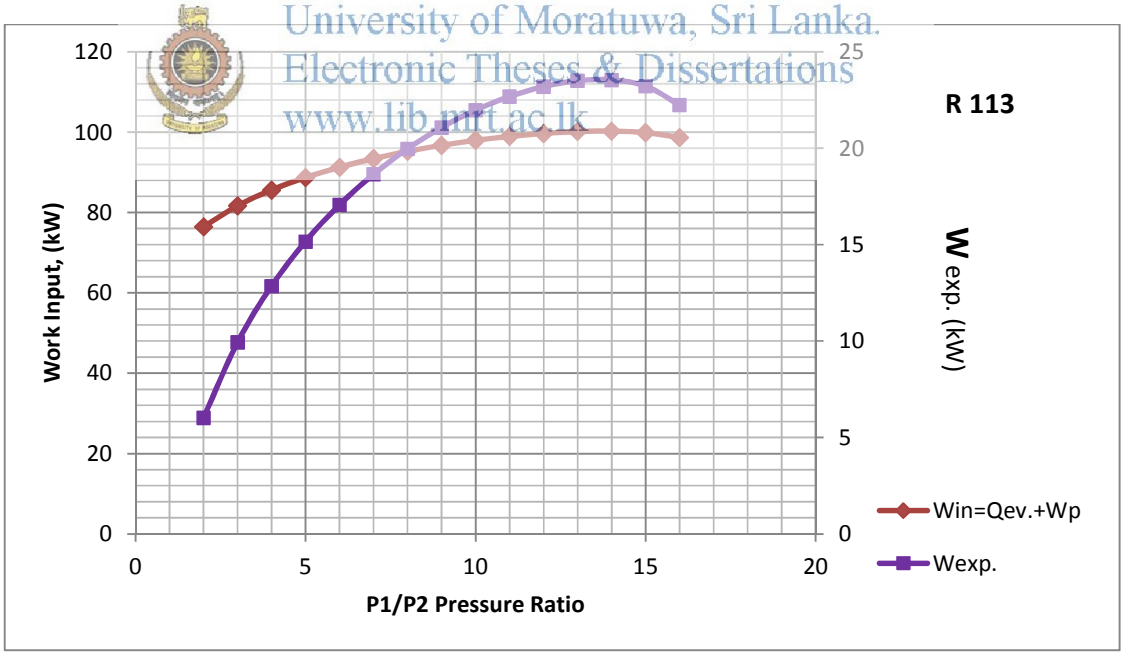
R113 as working fluid



Graph C.43: Variation of Work component with different Expander pressure ratios for R113

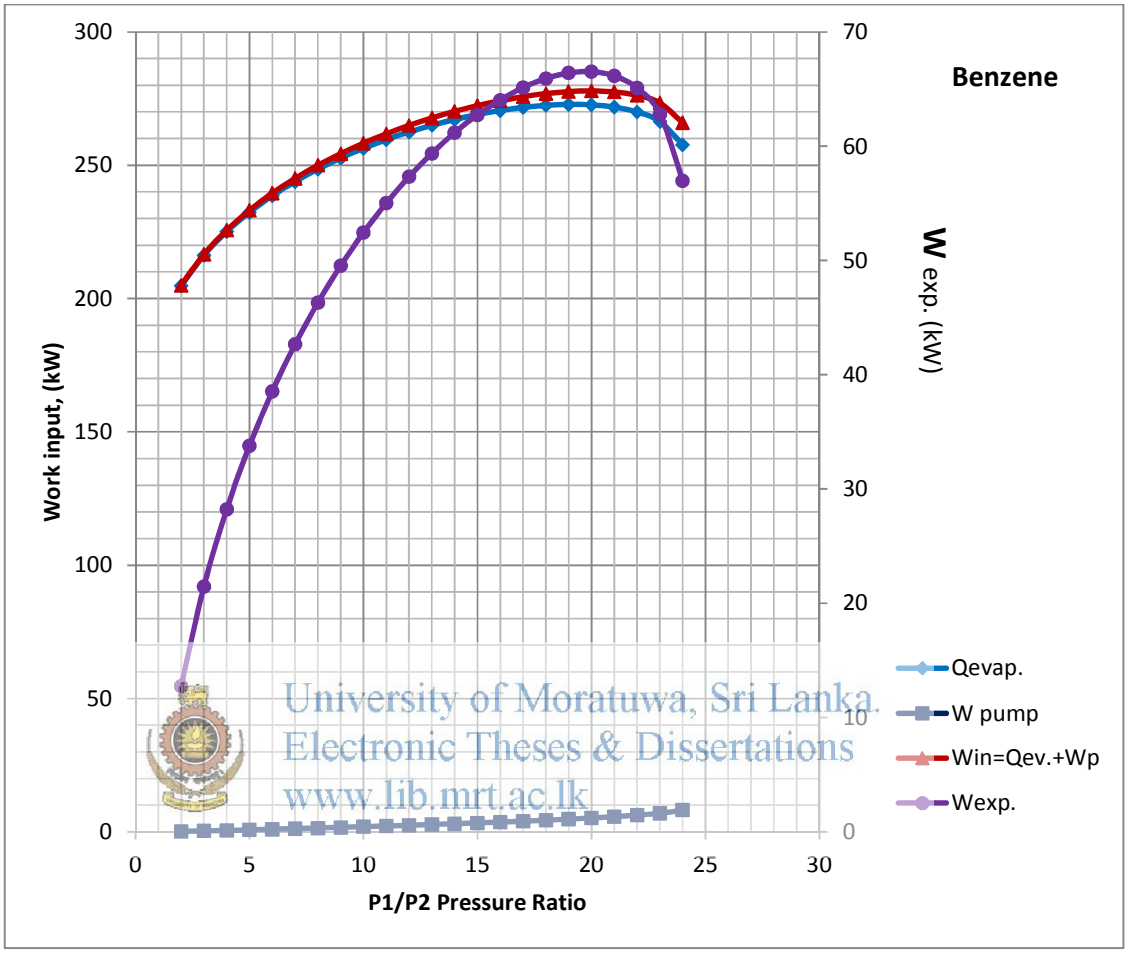


Graph C.44: Work Input and Efficiency variation with different Expander pressure ratios for R113

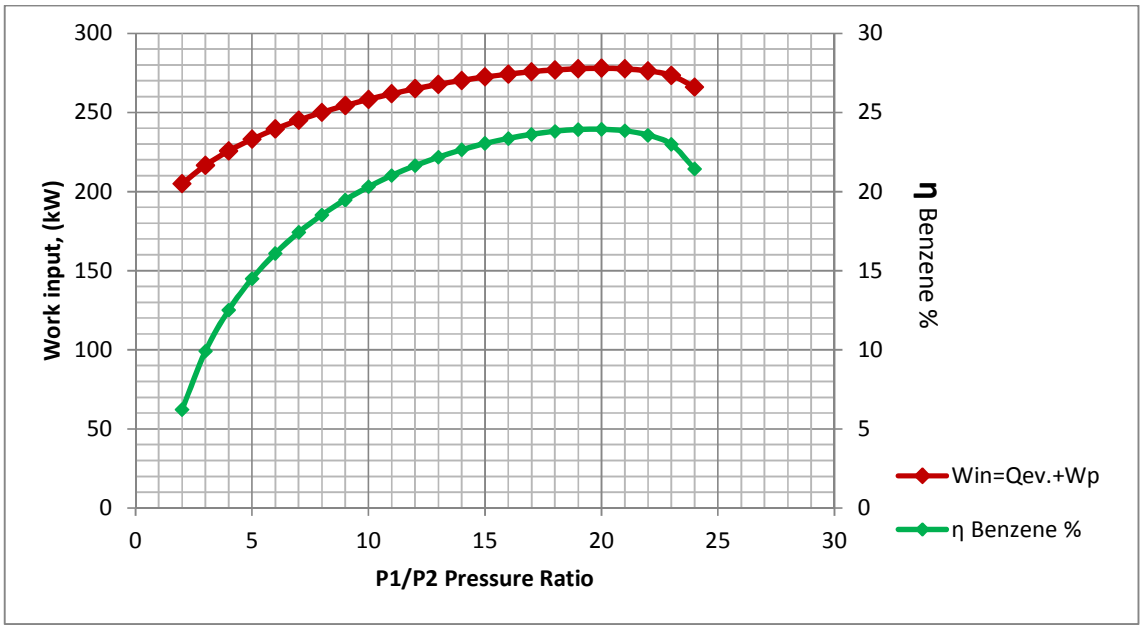


Graph C.45: Work Input and Work Output variation with different Expander pressure ratios for R113

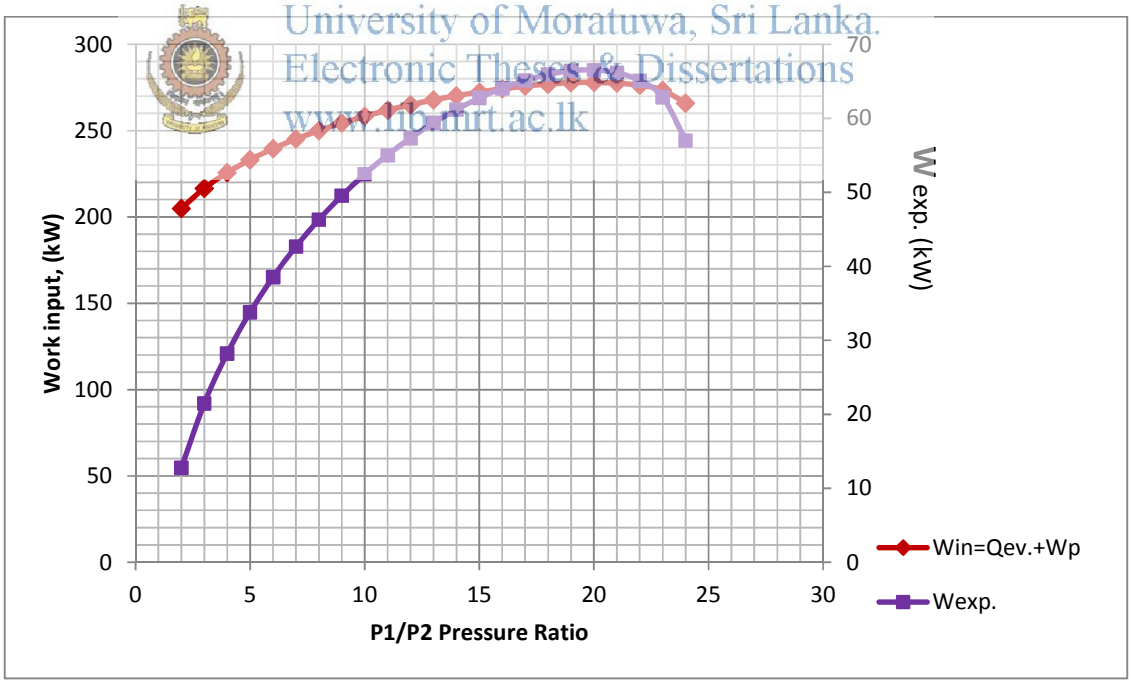
Benzene as working fluid



Graph C.46: Variation of Work component with different Expander pressure ratios for Benzene

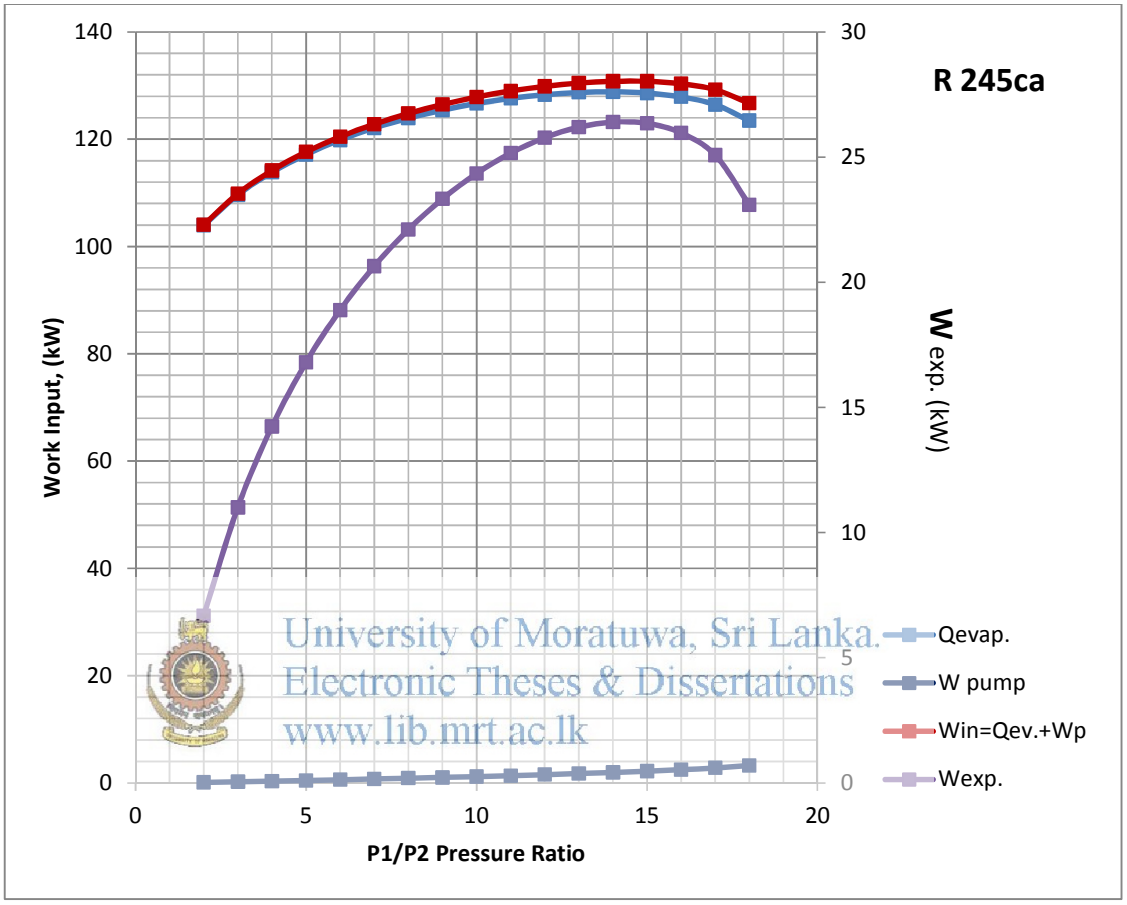


Graph C.47: Work Input and Efficiency variation with different Expander pressure ratios for Benzene

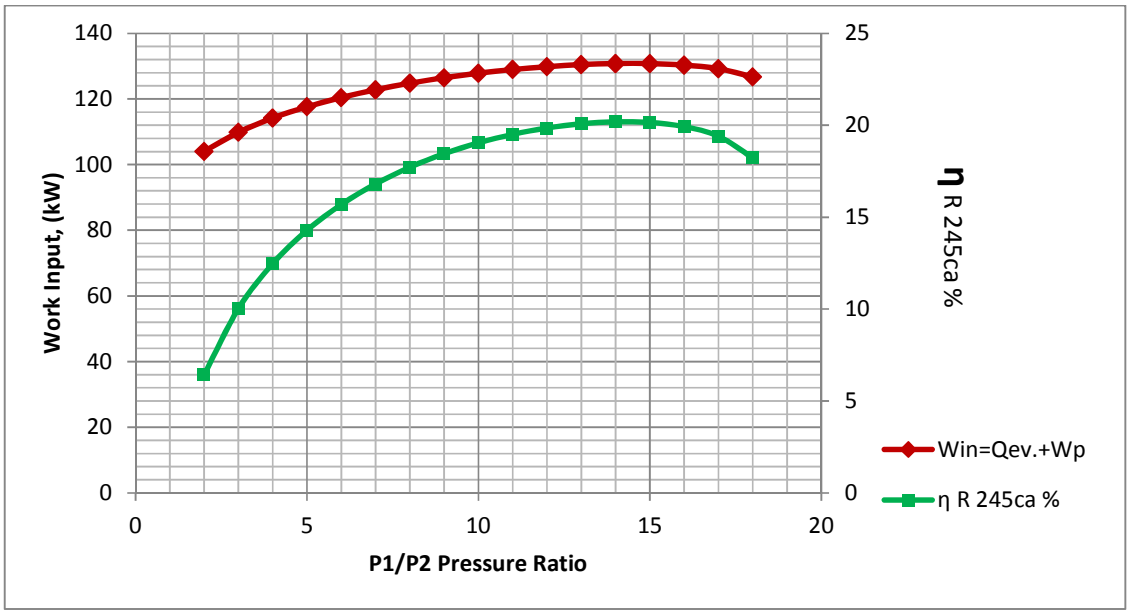


Graph C.48: Work Input and Work Output variation with different Expander pressure ratios for Benzene

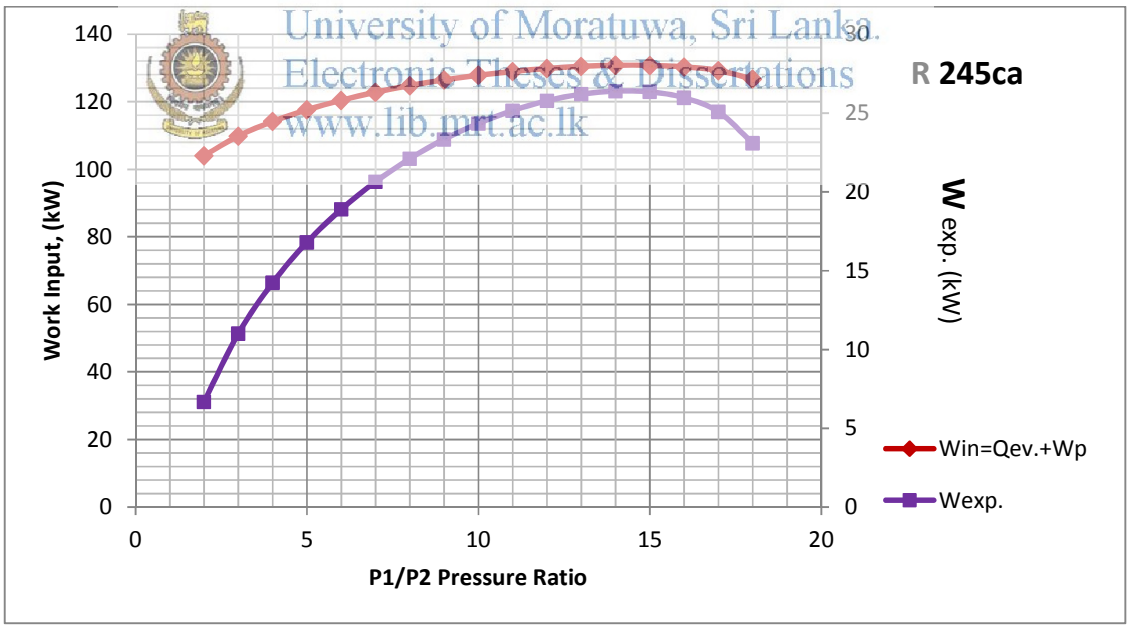
R245ca as working fluid



Graph C.49: Variation of Work component with different Expander pressure ratios for R245ca

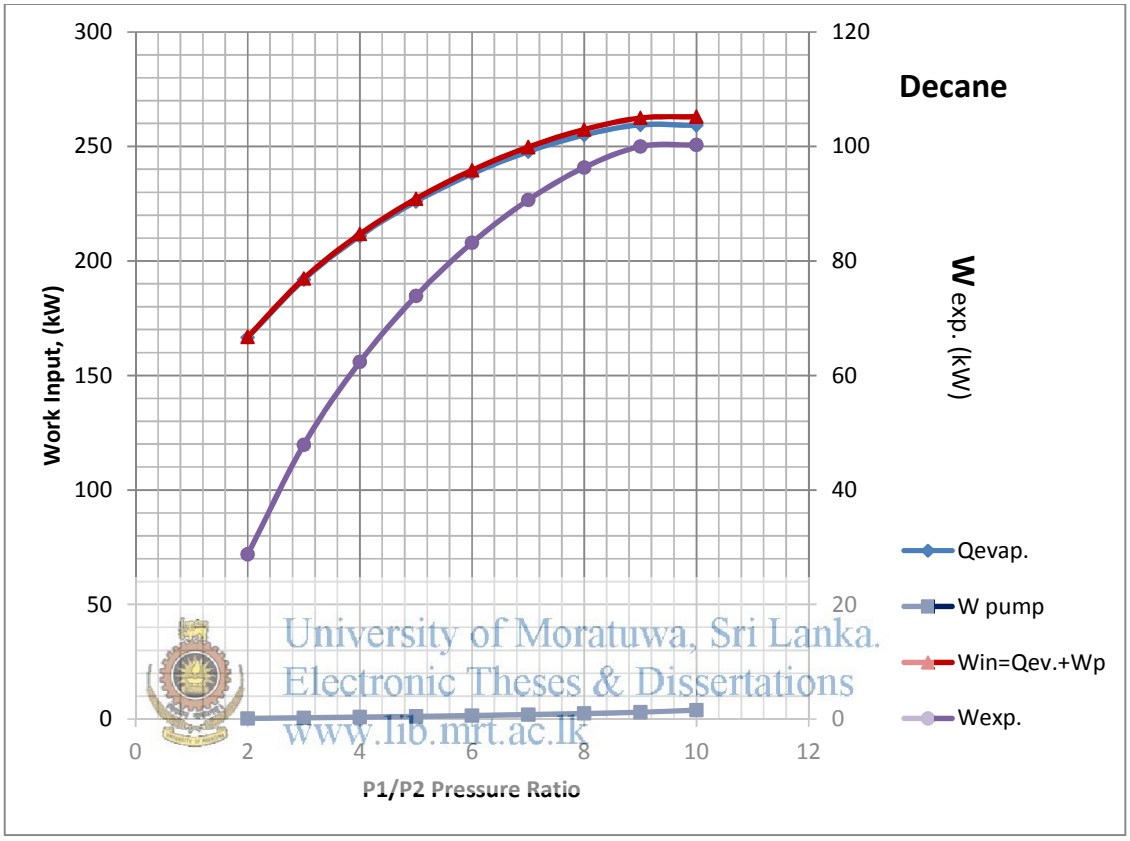


Graph C.50: Work Input and Efficiency variation with different Expander pressure ratios for R245ca

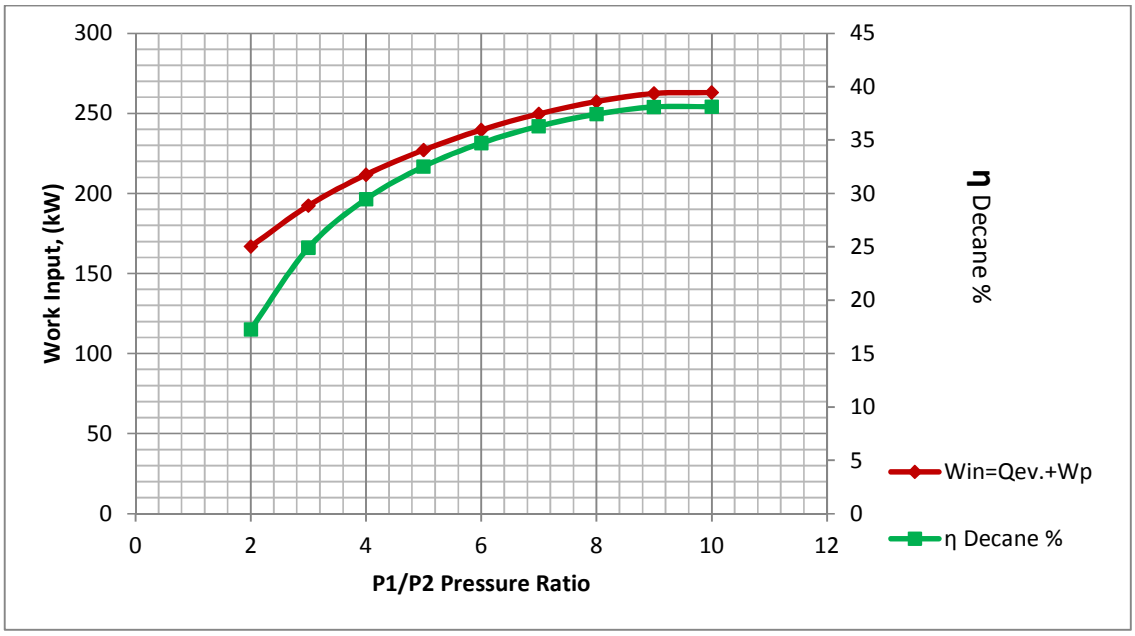


Graph C.51: Work Input and Work Output variation with different Expander pressure ratios for R245ca

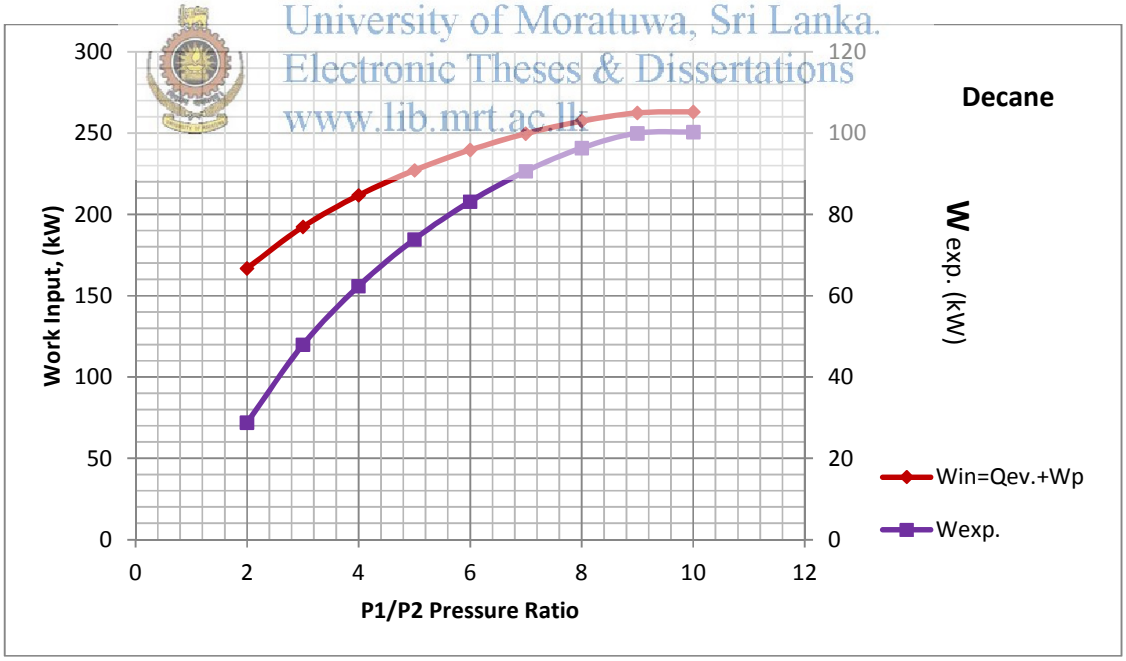
Decane as working fluid



Graph C.52: Variation of Work component with different Expander pressure ratios for Decane

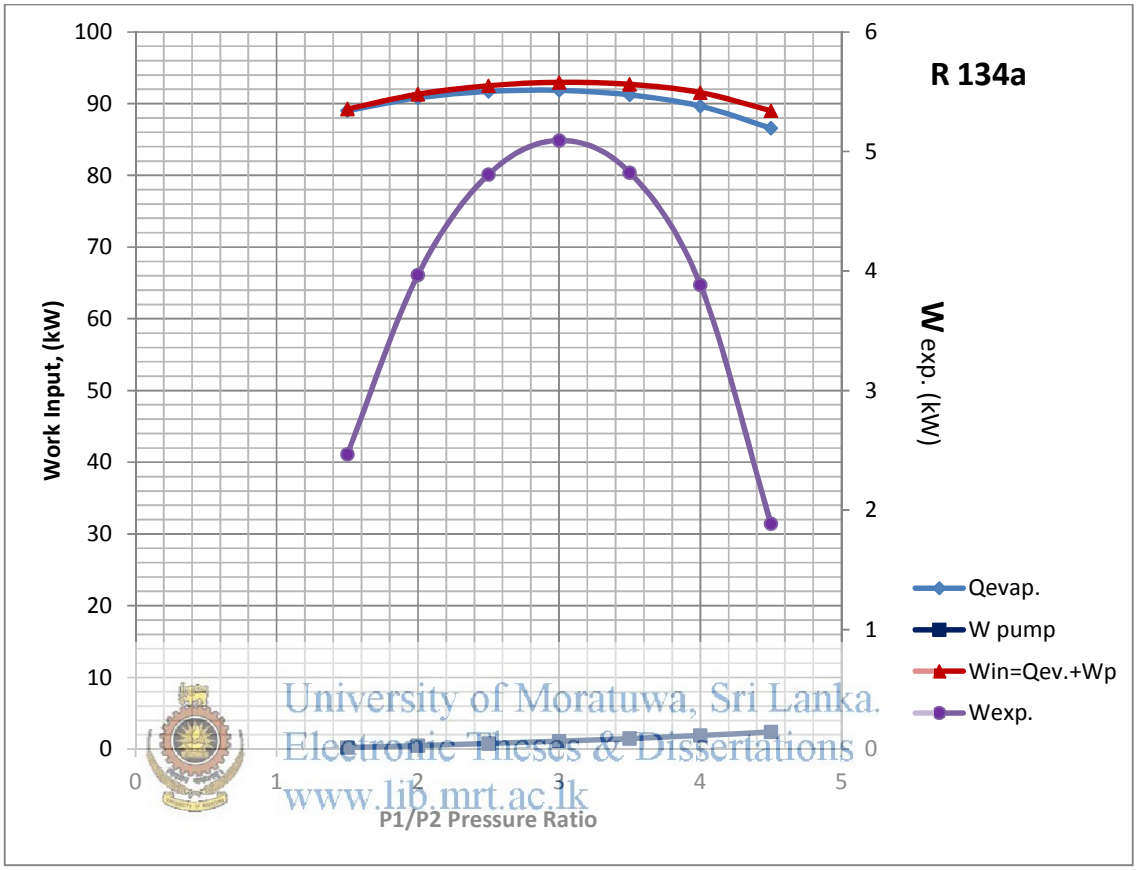


Graph C.53: Work Input and Efficiency variation with different Expander pressure ratios for Decane

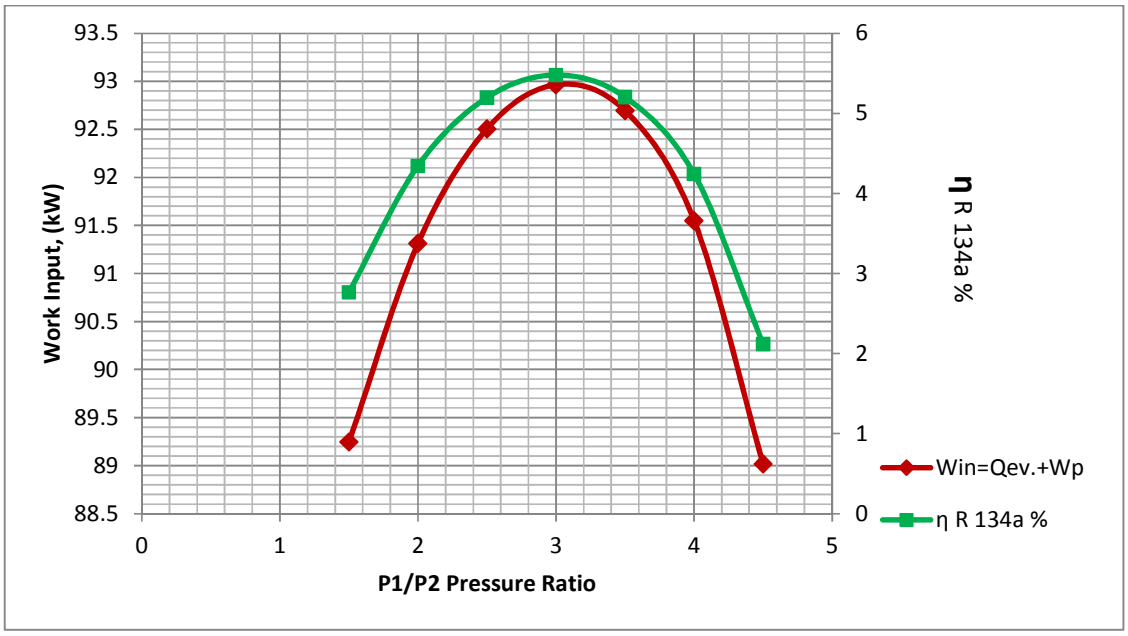


Graph C.54: Work Input and Work Output variation with different Expander pressure ratios for Decane

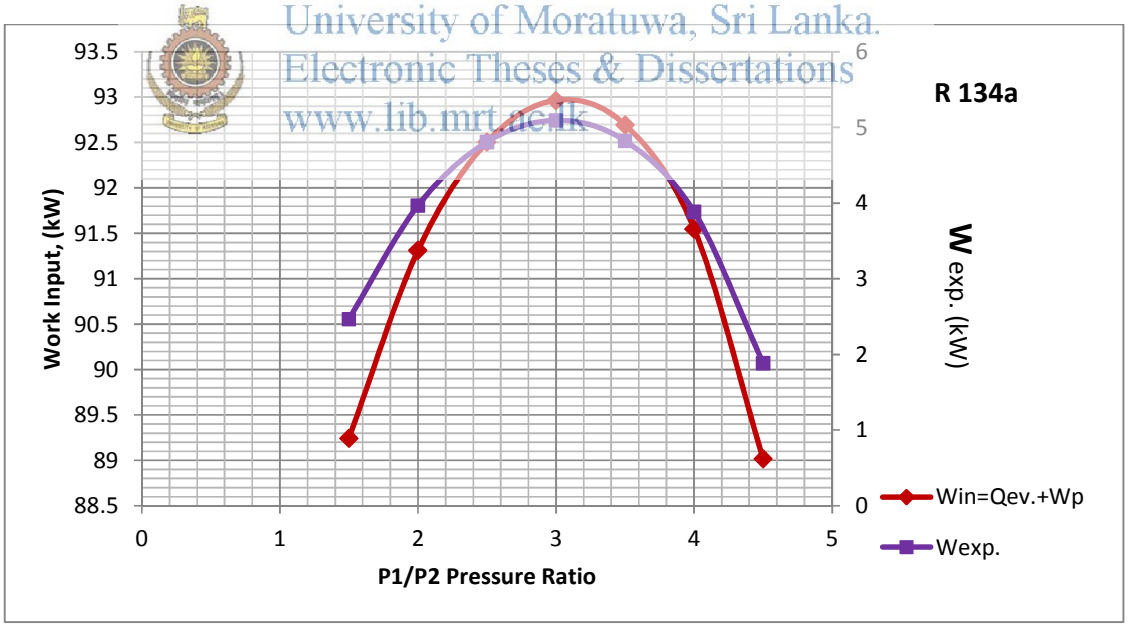
R134a as working fluid



Graph C.55: Variation of Work component with different Expander pressure ratios for R134a

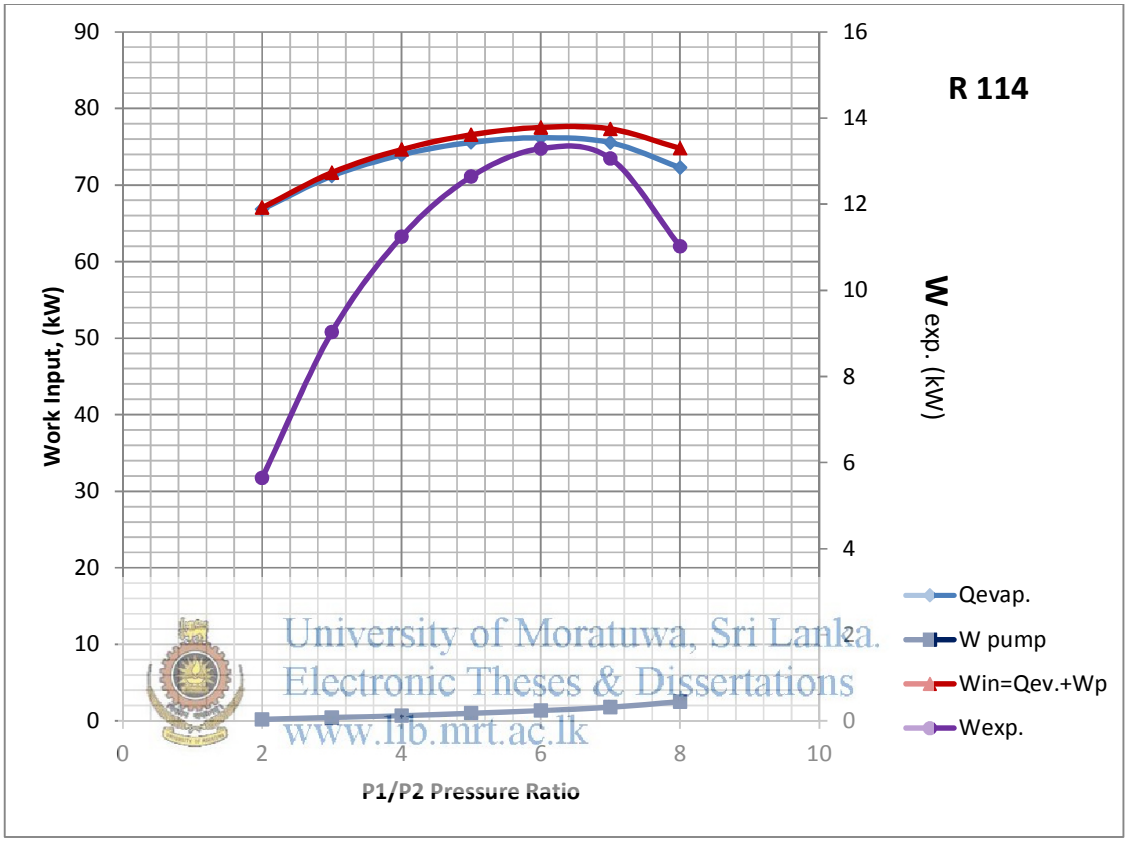


Graph C.56: Work Input and Efficiency variation with different Expander pressure ratios for R134a

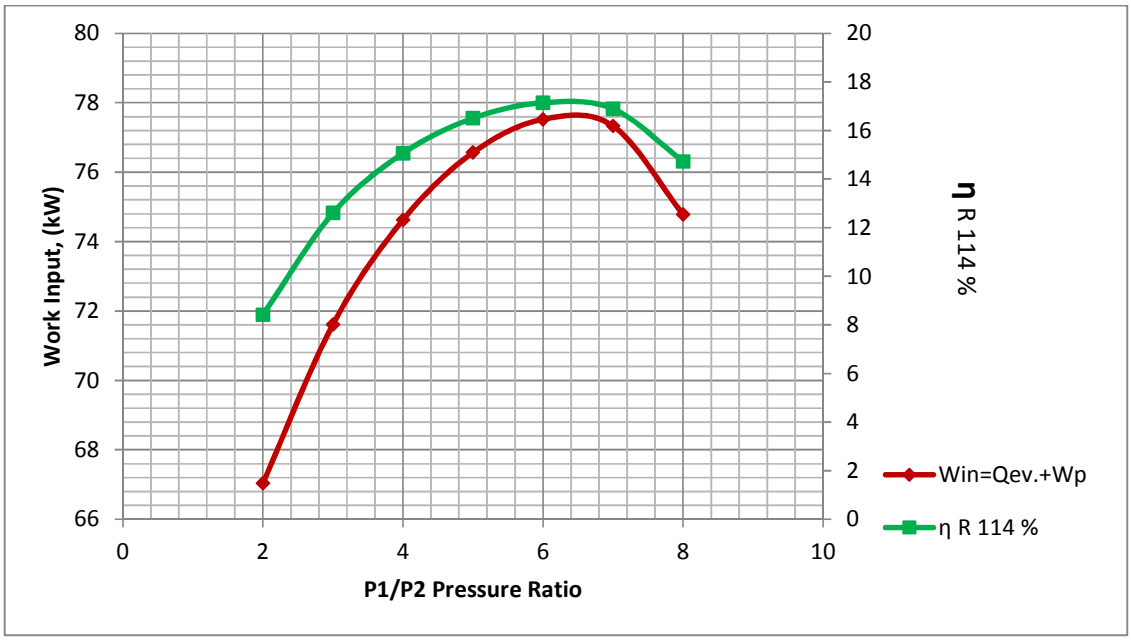


Graph C.57: Work Input and Work Output variation with different Expander pressure ratios for R134a

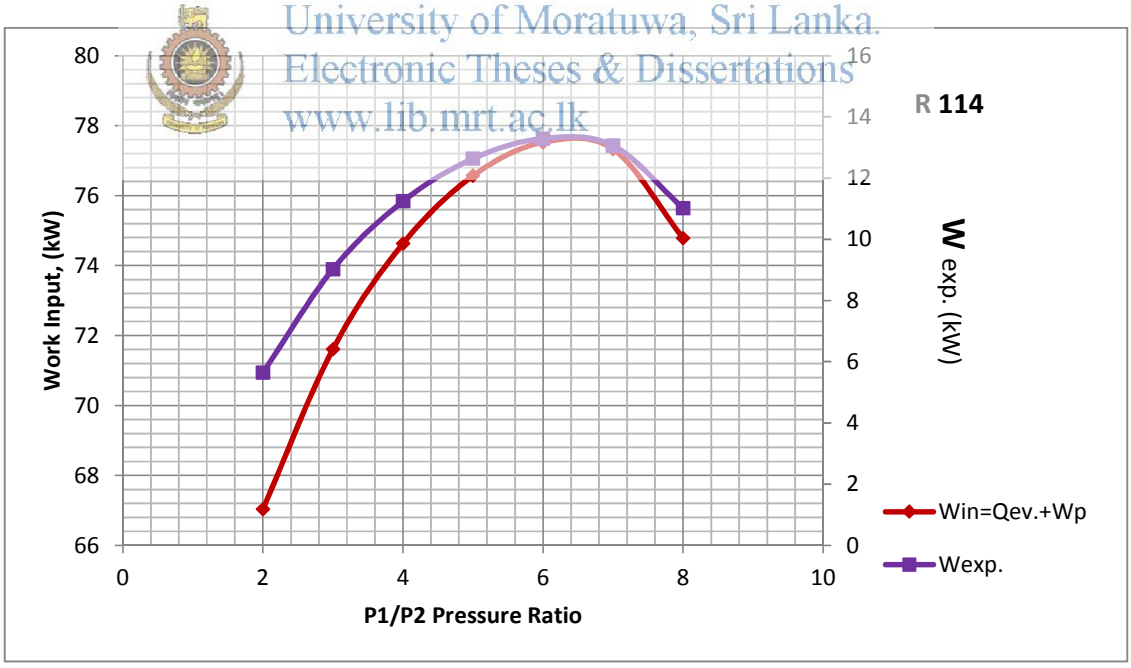
R114 as working fluid



Graph C.58: Variation of Work component with different Expander pressure ratios for R114

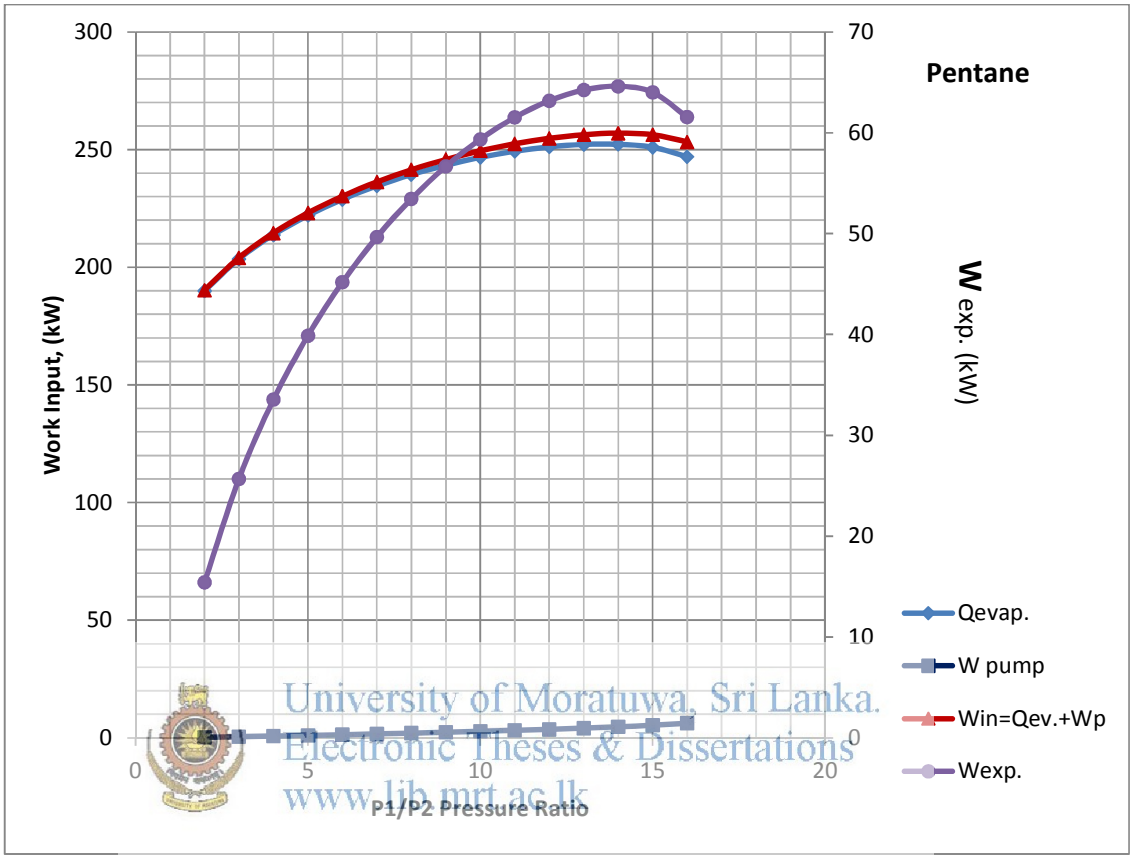


Graph C.59: Work Input and Efficiency variation with different Expander pressure ratios for R114

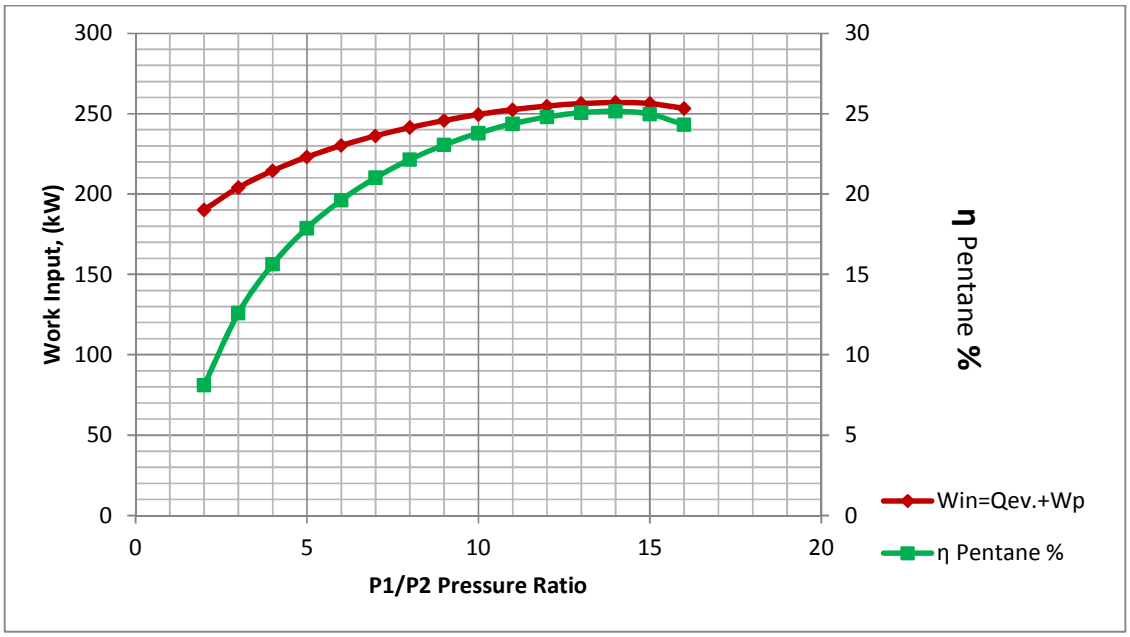


Graph C.60: Work Input and Work Output variation with different Expander pressure ratios for R114

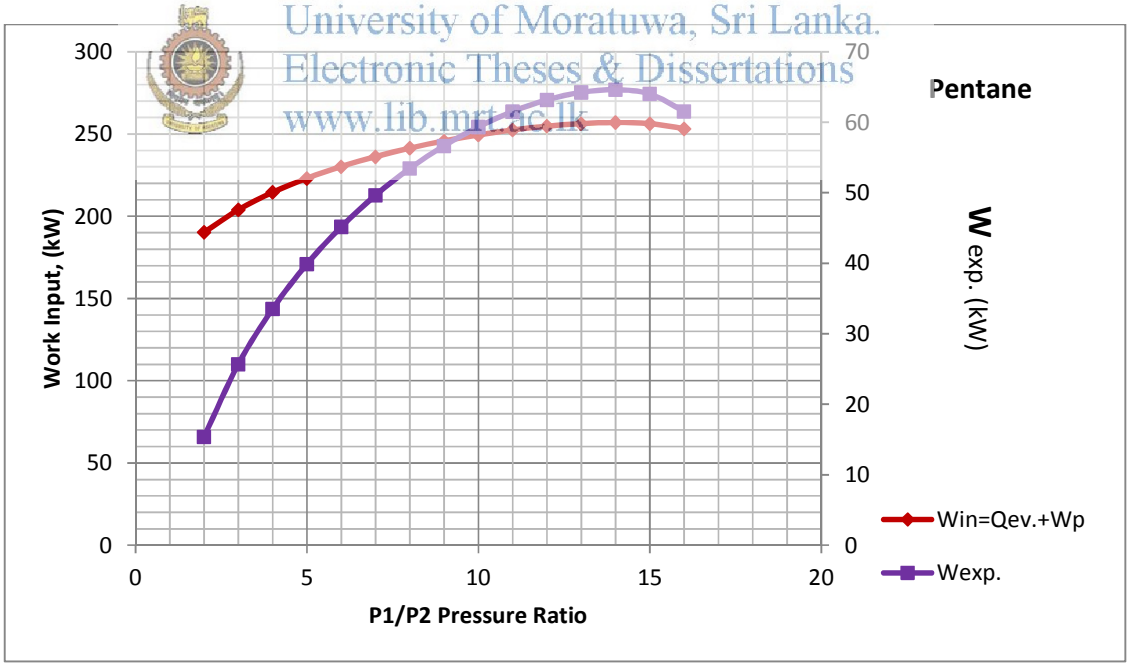
Pentane as working fluid



Graph C.61: Variation of Work component with different Expander pressure ratios for Pentane

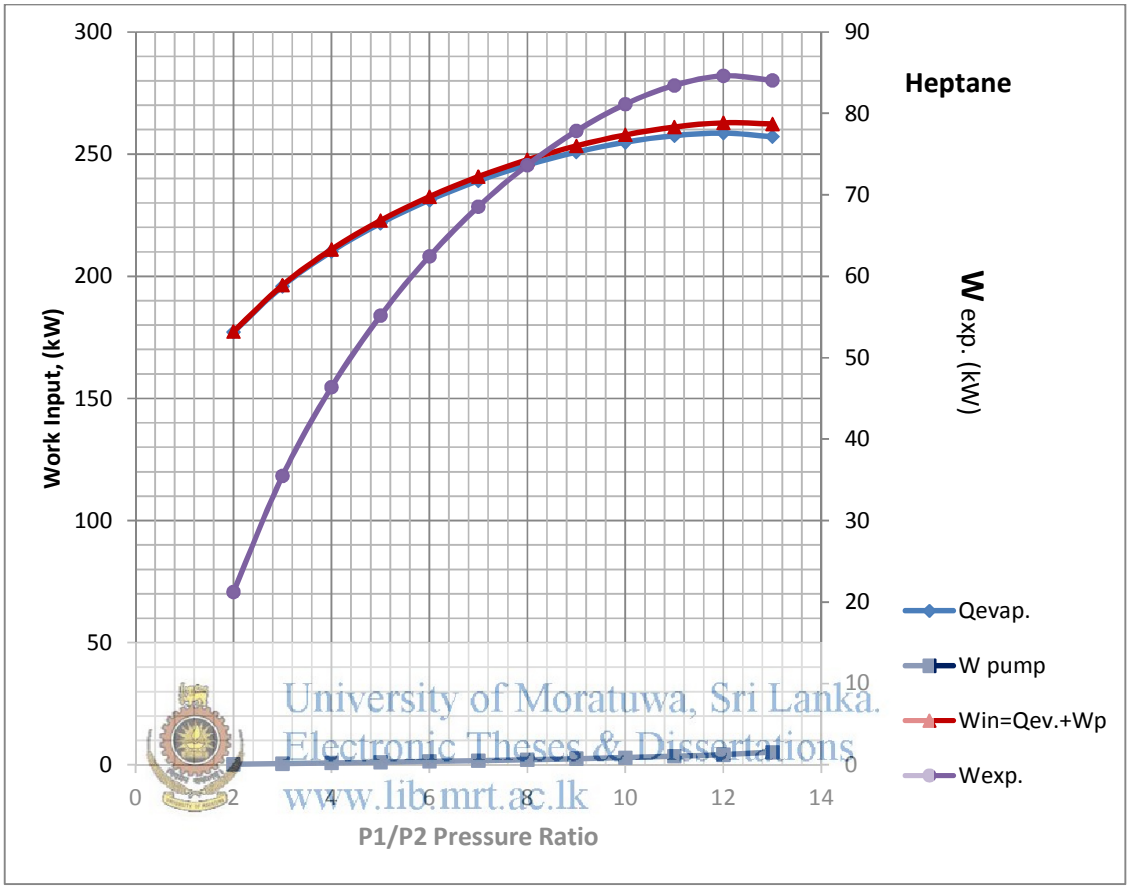


Graph C.62: Work Input and Efficiency variation with different Expander pressure ratios for Pentane

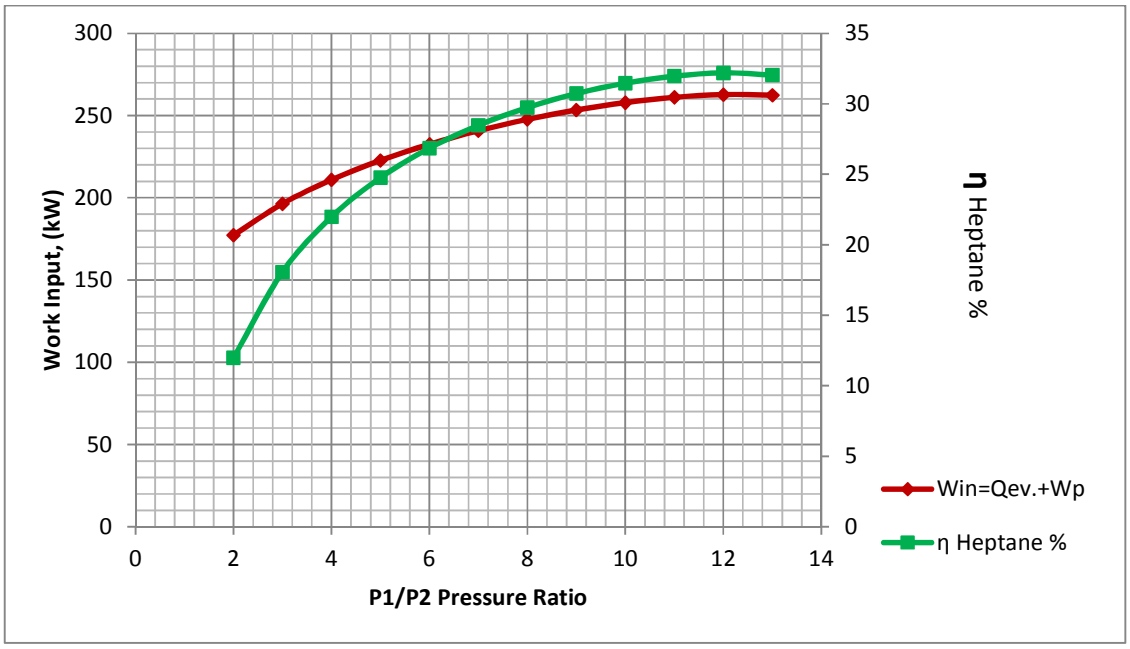


Graph C.63: Work Input and Work Output variation with different Expander pressure ratios for Pentane

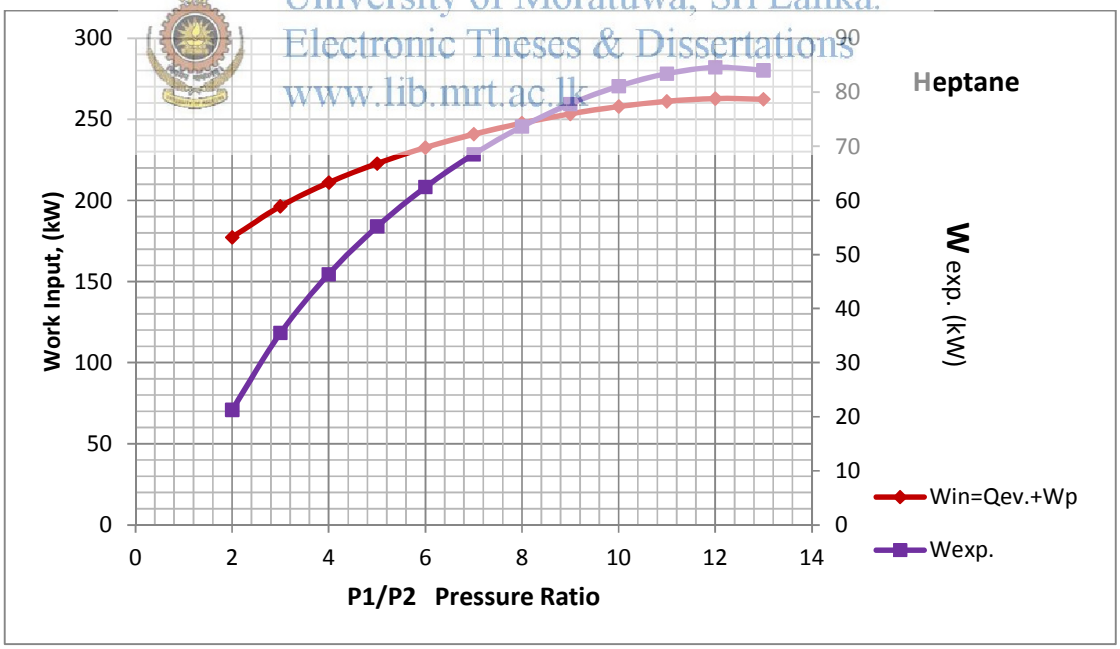
Heptane as working fluid



Graph C.64: Variation of Work component with different Expander pressure ratios for Heptane



Graph C.65: Work Input and Efficiency variation with different Expander pressure ratios for Heptane



Graph C.66: Work Input and Work Output variation with different Expander pressure ratios for Heptane

APPENDIX D

WORK OUTPUT CALCULATIONS FOR CASE STUDY

Following table shows the detailed calculations on work output of the expander.

Where;

Exh. Energy – Exhaust energy from heat source (kW)

Exh. T – Exhaust heat source average temperature (^{o}C)

Evap. Ext. T – Evaporator exiting/leaving temperature of organic fluid (^{o}C)

Evp. In – Evaporator in/entering temperature of organic fluid (^{o}C)

Eff. Evp. – Efficiency of evaporator

Q evap. In – Heat absorbed at the evaporator (kW)

hg evp. out – Saturated enthalpy at gaseous phase in the evaporator leaving fluid (KJ/kg)

hf evp. in - Saturated enthalpy at liquid phase in the evaporator entering fluid (KJ/kg)

Mass – Mass flow rate of the organic fluid (kg/s)

hg exp. out - Enthalpy at gaseous phase of the fluid leaving expander (KJ/kg)

η is – Isentropic efficiency of the expander

Wexp. – Work done at the expander (kW)

Table D.1: Sapugaskanda Power Station Exhaust Heat Recovery

Fluid	Exh. Enrgy	Exh. T	Evap. Ext T	Evp. In	Eff. Evp.	Qevp. In	hg evp. Out	hf evp. In	Mass kg/s	hg exp. Out	η is	W exp.
R123	10799.13	430-180	165	45	0.2	2159.826	462.95	248.325	10.06325	408.52	0.75	410.8072
R113	10799.13	430-180	165	45	0.2	2159.826	455.975	240.31	10.01473	388.1	0.75	509.8122
Pentane	10799.13	430-180	165	45	0.2	2159.826	719.47	189.585	4.076028	589.78	0.75	396.465

Table D.2: Lakvijaya Coal Plant Exhaust Heat Recovery

Fluid	Exh. Energy	Exh. T	Evap. Ext T	Evp. In	Eff. Evp.	Qevp. In	hg evp. Out	hf evp. In	Mass kg/s	hg exp. Out	η is	W exp.
R134a	17916.67	150-90	80	45	0.2	3583.334	280.67	115.8	21.7343	273.38	0.75	118.8323
R114	17916.67	150-90	80	45	0.2	3583.334	383.67	244.62	25.77011	364.365	0.75	373.119
R245fa	17916.67	150-90	80	45	0.2	3583.334	464.31	261.28	17.64928	439.3	0.75	331.0564
R245ca	17916.67	150-90	80	45	0.2	3583.334	326.37	109.365	16.51268	299.11	0.75	337.6017

Table D.3: Lakvijaya Coal Plant Continuous Blow down Heat Recovery

Fluid	Exh. Energy	Exh. T	Evap. Ext T	Evp. In	Eff. Evp.	Qevp. In	hg evp. Out	hf evp. In	Mass kg/s	hg exp. Out	η is	W exp.
R114	1723.446	275-100	100	45	0.200	344.689	392.960	244.620	2.324	364.365	0.750	49.833
R245fa	1723.446	275-100	100	45	0.200	344.689	477.670	261.280	1.593	439.300	0.750	45.840
R245ca	1723.446	275-100	100	45	0.200	344.689	341.040	109.365	1.488	299.110	0.750	46.788
R123	1723.446	275-100	100	45	0.200	344.689	439.770	248.770	1.805	408.520	0.750	42.297

Table D.4: Jaffna Diesel Plant Exhaust Heat Recovery

Fluid	Exh. Energy	Exh. T	Evap. Ext T	Evp. In	Eff. Evp.	Qevp. In	hg evp. Out	hf evp. In	Mass kg/s	hg exp. Out	η is	W exp.
Heptane	384.44	420-240	220	45	0.2	76.888	857.87	184.3	0.14415	536.915	0.75	27.47775
Benzene	384.44	420-240	220	90	0.2	76.888	562.19	18.947	0.141535	406.25	0.75	16.55325
Toluene	384.44	420-240	220	45	0.2	76.888	777.06	139.33	0.120565	540.375	0.75	21.40197

Table D.5: Keravalapitiya Plant Exhaust Heat Recovery

Fluid	Exh. Energy	Exh. T	Evap. Ext T	Evp. In	Eff. Evp.	Qevp. In	hg evp. Out	hf evp. In	Mass kg/s	hg exp. Out	η is	W exp.
R245ca	163838.43	500-160	145	45	0.2	32767.686	366.555	109.365	127.4065	299.11	0.75	6444.7
R123	163838.43	500-160	145	45	0.2	32767.686	459.495	248.325	155.1721	408.52	0.75	5932.422
R113	163838.43	500-160	145	45	0.2	32767.686	446.56	240.31	158.8736	388.1	0.75	6965.814
Pentane	163838.43	500-160	145	45	0.2	32767.686	695.16	189.585	64.81271	539.78	0.75	7552.949

Table D.6: Kelanithissa GT Plant Exhaust Heat Recovery

Fluid	Exh. Enrgy	Exh. T	Evap. Ext T	Evp. In	Eff. Evp.	Qevp. In	hg evp. Out	hf evp. In	Mass kg/s	hg exp. Out	η is	W exp.
R123	32790.3	470-180	165	45	0.2	6558.06	462.95	248.325	30.5559	408.52	0.75	1247.368
R113	32790.3	470-180	165	45	0.2	6558.06	455.975	240.31	30.40855	388.1	0.75	1547.985
Pentane	32790.3	470-180	165	45	0.2	6558.06	719.47	189.585	12.37638	589.78	0.75	1203.82

APPENDIX E

NET POSITIVE VALUE CALCULATIONS

Expected Turnover Calculation

Based on different tariff rates for unit price and expected annual running hours, expected annual turnover would change. Following tables are related to annual turnover calculation in different situation.

Table E.18: 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.**
Sapugaskanda Power Station	458.831	5256	2411615.504	14.00	33,762,617.05
Lakvijaya Coal Plant	335.807	5256	1765002.124	14.00	24,710,029.74
Jaffna Diesel Plant	24.730	5256	129980.769	14.00	1,819,730.77
Keravalapitiya Plant	6797.654	5256	35728470.860	14.00	500,198,592.04
Kelanithissa GT Plant	1393.187	5256	7322589.491	14.00	102,516,252.87
Lakvijaya Blowdown	44.850	5256	235732.026	14.00	3,300,248.37

Table E.19: 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.
Sapugaskanda Power Station	458.831	5256	2411615.504	15.00	36,174,232.55
Lakvijaya Coal Plant	335.807	5256	1765002.124	15.00	26,475,031.87
Jaffna Diesel Plant	24.730	5256	129980.769	15.00	1,949,711.54
Keravalapitiya Plant	6797.654	5256	35728470.860	15.00	535,927,062.90
Kelanithissa GT Plant	1393.187	5256	7322589.491	15.00	109,838,842.36
Lakvijaya Blowdown	44.850	5256	235732.026	15.00	3,535,980.40

Table E.20: 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.
Sapugaskanda Power Station	458.831	5256	2411615.504	15.40	37,138,878.76
Lakvijaya Coal Plant	335.807	5256	1765002.124	15.40	27,181,032.72
Jaffna Diesel Plant	24.730	5256	129980.769	15.40	2,001,703.85
Keravalapitiya Plant	6797.654	5256	35728470.86	15.40	550,218,451.25
Kelanithissa GT Plant	1393.187	5256	7322589.491	15.40	112,767,878.16
Lakvijaya Blowdown	44.850	5256	235732.026	15.40	3,630,273.21

Table E.21: Expected annual turnover at different 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. Turnover Rs.
Sapugaskanda Power Station	458.831	5256	2411615.504	15.00	36,174,232.55
Lakvijaya Coal Plant	335.807	6132	2059169.145	15.00	30,887,537.18
Jaffna Diesel Plant	24.730	5256	129980.769	15.00	1,949,711.54
Keravalapitiya Plant	6797.654	5256	35728470.860	15.00	535,927,062.90
Kelanithissa GT Plant	1393.187	3504	4881726.327	15.00	73,225,894.91
Lakvijaya Blowdown	44.850	6132	275020.698	15.00	4,125,310.46

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 identifies heat sources were mentioned in the tables as follows;

A - Sapugaskanda Power Station
B - Lakvijaya Coal Plant
C - Jaffna Diesel Plant
D - Keravalapitiya Plant
E - Kelanithissa GT Plant
F - Lakvijaya Boiler Blow Down

Table E.22: Scenario 1 – Electricity unit selling price Rs. 14.00, Interest Rate 8%

WHR Opp.	Total Investment Rs.	Total Overhead (OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Int. Rate %	NPV of Income	PV of Inv. After 5 years
A	131,560,000	1,315,600	33,762,617	32,447,017	8	129,551,531	(2,008,469)
B	97,240,000	972,400	24,710,030	23,737,630	8	94,777,473	(2,462,527)
C	8,125,000	81,250	1,819,731	1,738,481	8	6,941,250	(1,183,750)
D	1,591,200,000	15,912,000	500,198,592	484,286,592	8	1,933,615,937	342,415,937
E	327,600,000	3,276,000	102,516,253	99,240,253	8	396,237,554	68,637,554
F	14,625,000	146,250	3,300,248	3,153,998	8	12,593,001	(2,031,999)

Table E.23: Scenario 2 – Electricity unit selling price Rs. 15.00, Interest Rate 8%

WHR Opp.	Total Investment Rs.	Total Overhead (OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Int. Rate %	NPV of Income	PV of Inv. After 5 years
A	131,560,000	1,315,600	36,174,233	34,858,633	8	139,180,412	7,620,412
B	97,240,000	972,400	26,475,032	25,502,632	8	101,824,614	4,584,614
C	8,125,000	81,250	1,949,712	1,868,462	8	7,460,225	(664,775)
D	1,591,200,000	15,912,000	535,927,063	520,015,063	8	2,076,269,361	485,069,361
E	327,600,000	3,276,000	109,838,842	106,562,842	8	425,474,530	97,874,530
F	14,625,000	146,250	3,535,980	3,389,730	8	13,534,211	(1,090,789)

Table E.24: Scenario 3 – Electricity unit selling price Rs. 15.40, Interest Rate 8%

WHR Opp.	Total Investment Rs.	Total Overhead (OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Int. Rate %	NPV of Income	PV of Inv. After 5 years
A	131,560,000	1,315,600	37,138,879	35,823,279	8	143,031,965	11,471,965
B	97,240,000	972,400	27,181,033	26,208,633	8	104,643,471	7,403,471
C	8,125,000	81,250	2,001,704	1,920,454	8	7,667,815	(457,185)
D	1,591,200,000	15,912,000	550,218,451	534,306,451	8	2,133,330,731	542,130,731
E	327,600,000	3,276,000	112,767,878	109,491,878	8	437,169,321	109,569,321
F	14,625,000	146,250	3,630,273	3,484,023	8	13,910,694	(714,306)

Table E.25: Scenario 4 – Electricity unit selling price Rs. 14.00, Interest Rate 10%

WHR Opp.	Total Investment Rs.	Total Overhead (OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Int. Rate %	NPV of Income	PV of Inv. After 5 years
A	131,560,000	1,315,600	33,762,617	32,447,017	10	122,999,723	(8,560,277)
B	97,240,000	972,400	24,710,030	23,737,630	10	89,984,293	(7,255,707)
C	8,125,000	81,250	1,819,731	1,738,481	10	6,590,210	(1,534,790)
D	1,591,200,000	15,912,000	500,198,592	484,286,592	10	1,835,827,206	244,627,206
E	327,600,000	3,276,000	102,516,253	99,240,253	10	376,198,638	48,598,638
F	14,625,000	146,250	3,300,248	3,153,998	10	11,956,135	(2,668,865)

Table E.26: Scenario 5 – Electricity unit selling price Rs. 15.00, Interest Rate 10%

WHR Opp.	Total Investment Rs.	Total Overhead (OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Int. Rate %	NPV of Income	PV of Inv. After 5 years
A	131,560,000	1,315,600	36,174,233	34,858,633	10	132,141,643	581,643
B	97,240,000	972,400	26,475,032	25,502,632	10	96,675,039	(564,961)
C	8,125,000	81,250	1,949,712	1,868,462	10	7,082,939	(1,042,061)
D	1,591,200,000	15,912,000	535,927,063	520,015,063	10	1,971,266,220	380,066,220
E	327,600,000	3,276,000	109,838,842	106,562,842	10	403,957,013	76,357,013
F	14,625,000	146,250	3,535,980	3,389,730	10	12,849,745	(1,775,255)

Table E.27: Scenario 6 – Electricity unit selling price Rs. 14.00, Interest Rate 12%

WHR Opp.	Total Investment Rs.	Total Overhead (OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Int. Rate %	NPV of Return	PV of Inv. After 5 years
A	131,560,000	1,315,600	33,762,617	32,447,017	12	116,964,235	(14,595,765)
B	97,240,000	972,400	24,710,030	23,737,630	12	85,568,843	(11,671,157)
C	8,125,000	81,250	1,819,731	1,738,481	12	6,266,834	(1,858,166)
D	1,591,200,000	15,912,000	500,198,592	484,286,592	12	1,745,744,782	154,544,782
E	327,600,000	3,276,000	102,516,253	99,240,253	12	357,738,902	30,138,902
F	14,625,000	146,250	3,300,248	3,153,998	12	11,369,458	(3,255,542)

Table E.28: Scenario 7 – Electricity unit selling price Rs. 15.00, Interest Rate 10% and Running hours are varied depending on actual situation

WHR Opp.	Total Investment Rs.	Total Overhead (OH) Cost 0.1% from Inv.	Exp. Turnover (TO) Rs.	Annual Return (TO-OH) Rs.	Int. Rate %	NPV of Income	PV of Inv. After 5 years
A	131,560,000	1,315,600	36,174,232	34,858,633	10	132,141,643	581,643
B	97,240,000	972,400	30,887,537	29,915,137	10	113,401,906	16,161,906
C	8,125,000	81,250	1,949,711	1,868,462	10	7,082,939	(1,042,061)
D	1,591,200,000	15,912,000	535,927,062	520,015,063	10	1,971,266,220	380,066,220
E	327,600,000	3,276,000	73,225,894	69,949,895	10	265,165,136	(62,434,864)
F	14,625,000	146,250	4,125,310	3,979,060	10	15,083,770	458,770