Università degli Studi di Trieste
Corso di Dottorato di Ricerca in Tecnologie Chimiche ed Energetiche

Analysis of Cogeneration Powered Absorption Chiller Systems in Remote Tropical Areas

Dottorando
Stephen Chijioke Nwanya

Anno accademico
2006-2007

Target of the research

The study focuses on developing a technology for meeting the energy needs of a tropical remote area, using minimal consumption of energy resource and increase energy efficiency, especially utilizing the waste heat to generate cooling effect.

Introduction

Characteristic problems of a typical Nigerian remote area in the tropics include:

- susceptibility to grid-connected electricity supplies either unavailable, unreliable or for most of the inhabitants unaffordable;
- in terms of economic activity, is predominately populated by farmers living in difficult terrain and
- the climate condition has preponderance of high ambient temperature.

Considering the increasing cost of fuel, the last two characteristic problems draw attention to the necessity for cold generation independent of grid electricity.

Introduction

The first characteristic problem underscores need for sustainable alternative energy mix solution.

Paradoxically, Nigeria has abundant energy resources and the citizens face serious insufficiency problems.

Some data

Population of Nigeria: 140 million inhabitants
Installed power capacity: 6 GW

Population of Italy: 56 million inhabitants
Installed power capacity: 84 GW

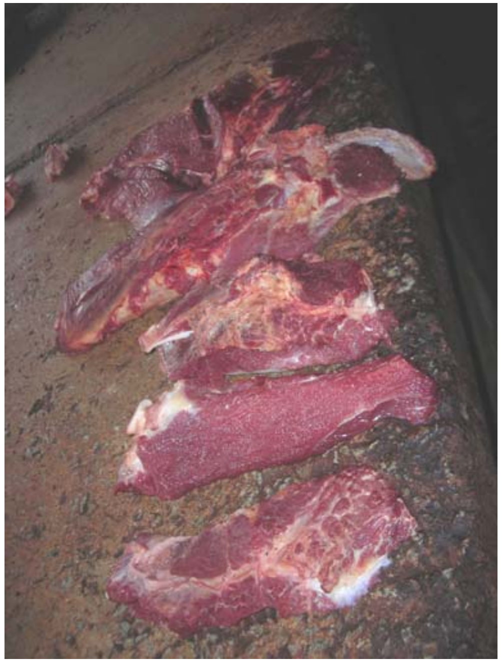
Typical perishable products from remote areas

Fresh tomato fruits in wooden baskets and sealed with paper as traditional transit preservation method

Vegetable

Garden egg fruit

Meat



Other Vegetables

…from the newspapers

- Energy crisis killing tourism in Cross River
- …Museum groans under two-month blackout

[The Sun, May 15, 2008]

- Nigeria: Total Blackout Looms - Power Supply Now Lowest Ever [This Day, Feb. 11, 2008]
- Nigeria: Nationwide Blackout Worsens As Funding Stalls Repairs [This Day, May 14, 2008]

Question!

The basic question now is which alternative energy technology can satisfy the energy scenario for the remote area:

- with extended resource utility;
- enhance standard of living and
- achieve savings in cost monetarily and environmentally?

Micro-gas turbine – Capstone 60

Introduction

Scientific efforts were made in the past to improvise alternative conventional cooling (storage) system using local solid absorbent materials. The envisaged storage system was limited by heat transfer problems.

Under this circumstance, micro-gas turbine, (MGT) system providing both power and waste heat is being proposed as viable alternative technology.

The waste heat recovered will be useful to run an absorption refrigeration chiller system, thus satisfying the necessity for cold generation (preservation & comfort).

Introduction

At present in Nigeria, cogeneration integrated absorption refrigeration chiller is uncommon system.
In view of this there is need to determine relevant thermo-physical properties, working conditions together with the economy of heat delivery for better efficiency of the integrated system.
This is essence of the analytical study on the cogeneration powered absorption chiller system.

Purpose of study

The purpose of this study include:

- point out advantages of cold availability;
- analyze available technologies to provide cold and to provide electricity in remote locations; provide "easy to handle" information regarding the new technologies preferably in language spoken by technicians;
- develop a thermoeconomic analysis of a small scale microturbine-absorption chiller cogeneration plant.

Specific objectives

The following specific objectives are pursued:

- estimation of optimal thermodynamic property conditions for absorption refrigeration system;
- estimation of the unit cost of thermal energy supply and;
- determination of whether cogeneration will provide substantial reductions in annual energy bill and justify the required capital investment.

Methodology

•energy balances,

•mass conservation,

• exergy analysis and

•thermoeconomic principles are sequentially employed in order to realize the set objectives.

In the course of analytical work, a simple Libr/H_20 absorption chiller system was configured using set of thermodynamic equations and operated at steady state conditions. An important tool for this work is Engineering Equation Solver, EES computer software.

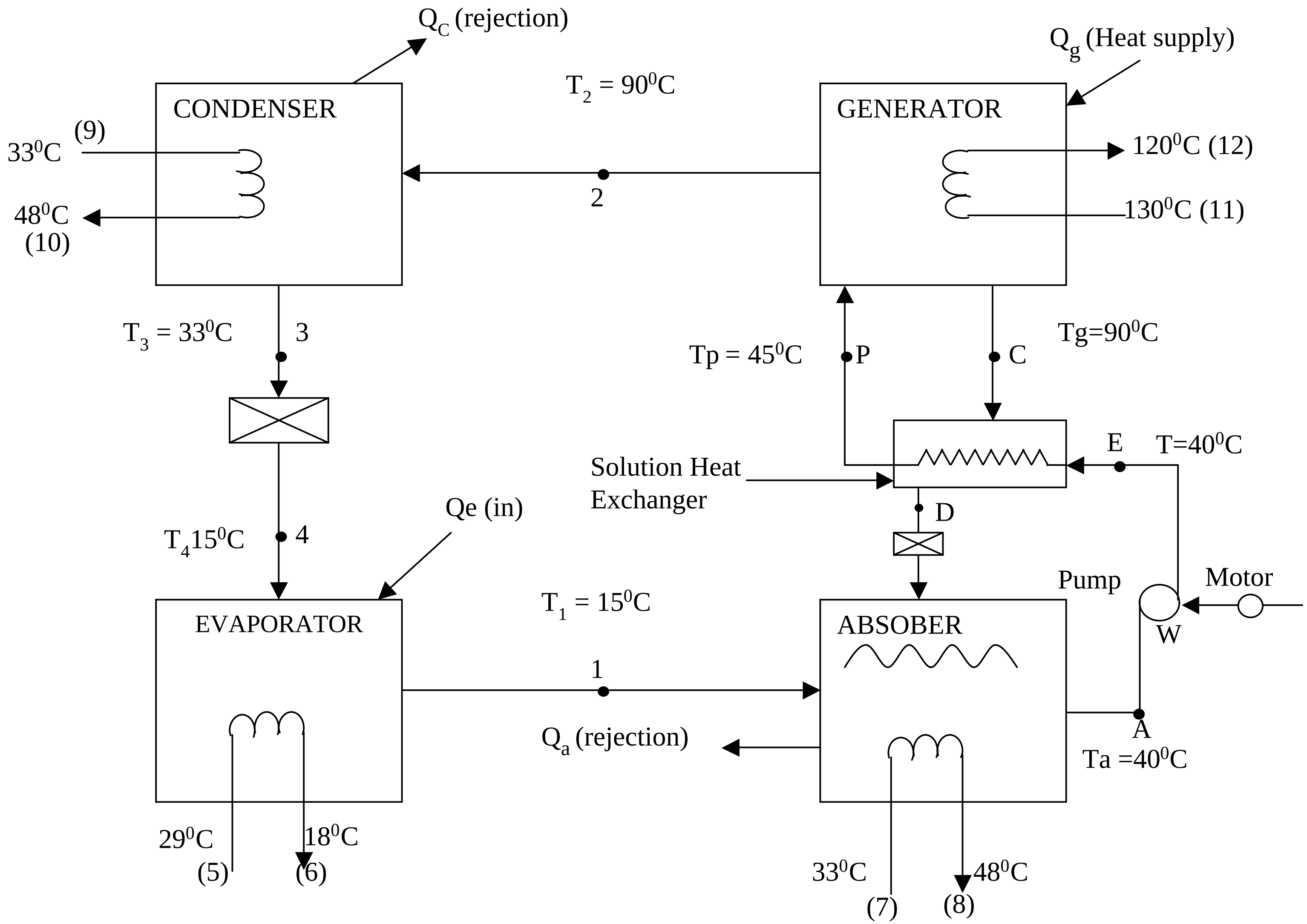
Modelling a simple absorption refrigeration system

To build up system, two important circuits are defined:

•The heat addition circuit consists of evaporator service side temperature and evaporator absorption side temperature

•The heat loss circuit comprises condenser absorption side temperature and condensing side temperature.

Once these temperatures are established the mixture chamber primary properties can be determined from Pressure(P)-Temperature(T)-Concentration(X), PTX diagram or built-in EES data base.

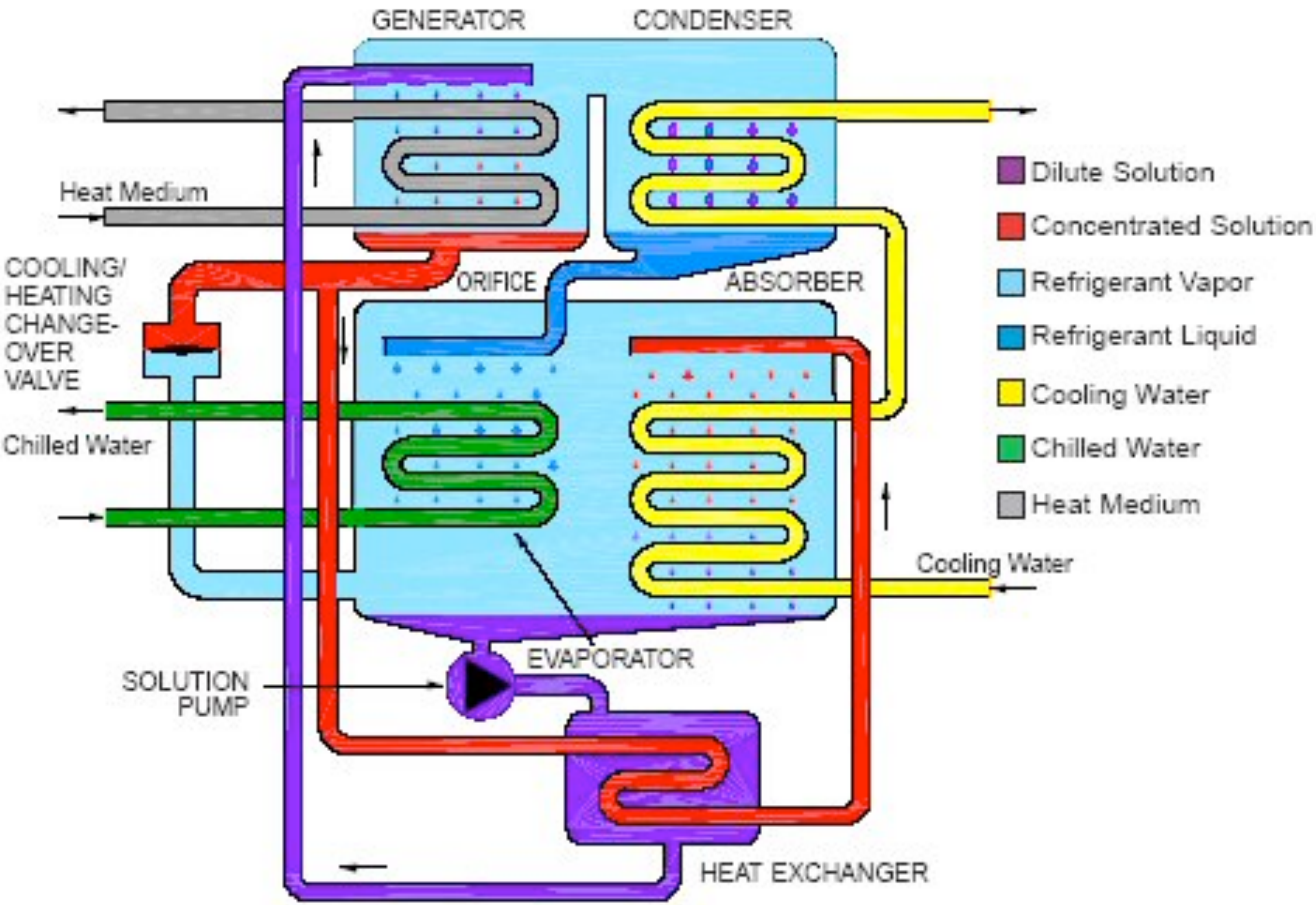


Simplified schematic of a Absorption Refrigeration Cycle

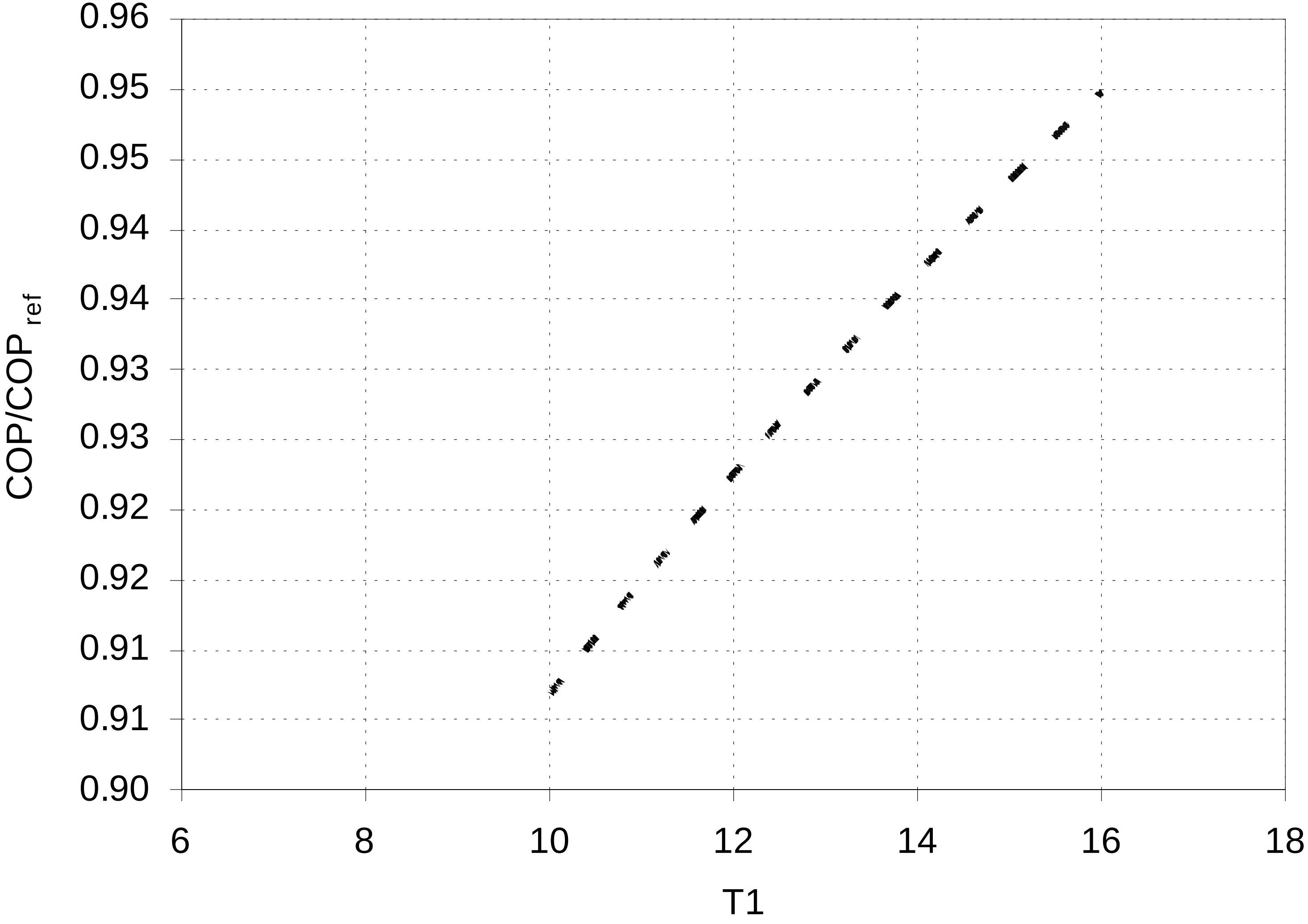
Mechanism of operation of the absorption chiller

The system is energized by a heat medium, steam at 130 ^{0}C from recuperator of a micro-gas turbine.
The chiller uses a solution of lithium bromide and water, under a vacuum, as absorbent and refrigerant, respectively.
The operation mechanism is such that keeping the evaporator temperature lower than refrigeration load temperature, it is possible for refrigerant to extract sensible heat from the load.

Detailed operation of absorption Chiller



Example of sensitivity analysis
Influence of evaporator temperature, T1 on COP



Characteristics of some prime movers used for cogeneration

	Steam turbine	**Spark ignition engines**	**Gas turbines**	**Micro-turbines**	**Stirling engines**	**Fuel cells**
Capacity range	50kW–500 MW	3kW – 6MW	250kW – 50MW	15kW – 300kW	1kW – 1.5MW	5kW – 2MW
Fuel used	Any	Gas, biogas, liquid fuels, propane	Gas, propane, distillate oils biogas	Gas, propane, distillate oils biogas	Any (gas, alcohol, butane, biogas)	Hydrogen and fuels containing hydrocarbons
Efficiency electrical (%)	7 – 40	25 – 43	25 – 42	15 – 30	~40	37 – 60
Efficiency overall (%)	60 – 80	70 – 92	65 – 87	60 – 85	65 – 85	85 – 90
Heat to Power ratio	0.1– 0.5	0.5 – 0.7	0.2 – 0.8	1.2 – 1.7	1.2 – 1.7	0.8 – 1.1
CO_2 emissions (kg/MWh)	c	500 – 620	580 – 680	720	672[d]	430 – 490
NO_X emissions (kg/MWh)	c	0.2 – 1.0	0.3 – 0.5	0.1	0.23[d]	0.005 – 0.01
Availability (%)	90 – 95	95	96 – 98	98	N/A	90 – 95
Part load Performance	Poor	Good	Fair	Fair	Good	Good
Life cycle (year)	25 – 35	20	20	10	10	10 – 20
Average cost Investment (S/kW)	1000 – 2000	800 – 1600	450 – 950	900 – 1500	1300 – 2000	2500 – 3500
Operating and Maintenances cost ($/kWh)	0.004	0.0075– 0.015	0.0045 – 0.0105	0.01 – 0.02	N/A	0.007 – 0.05

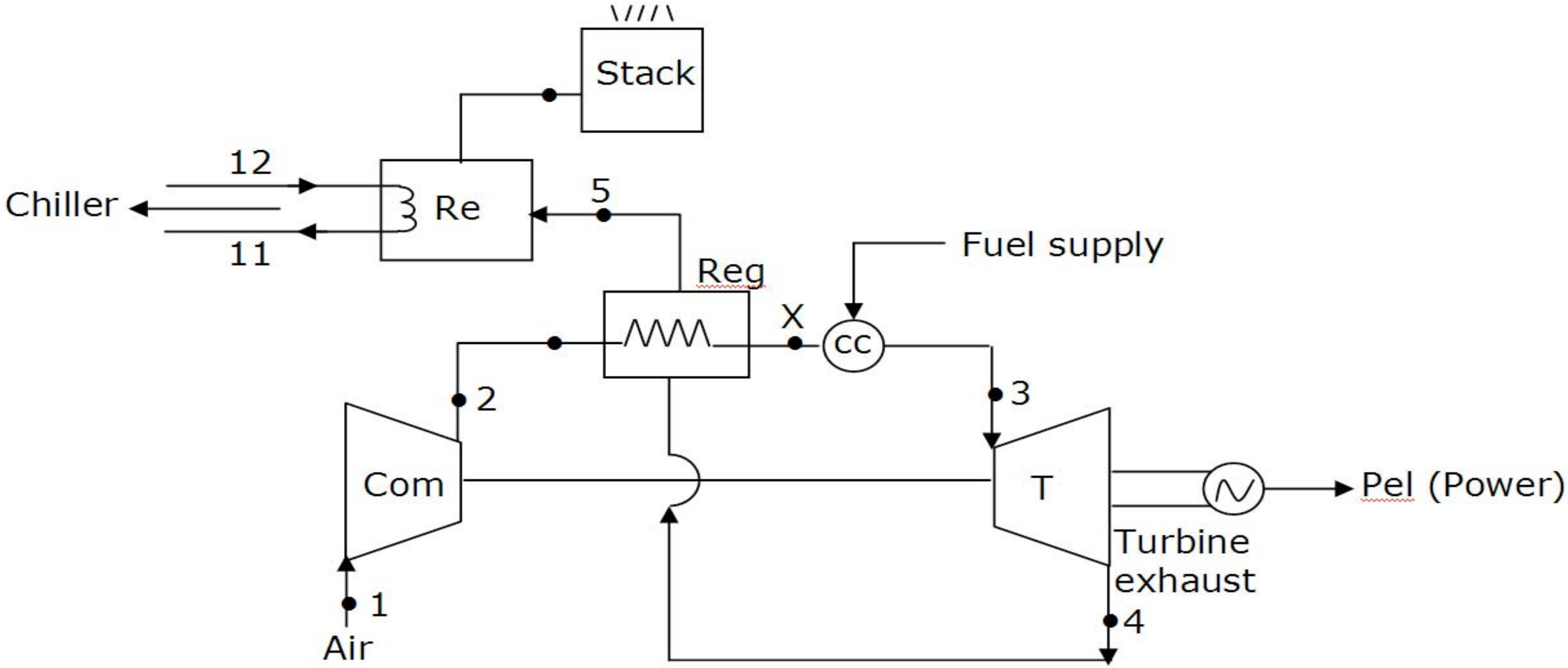
Modelling micro-gas turbine

Assumptions

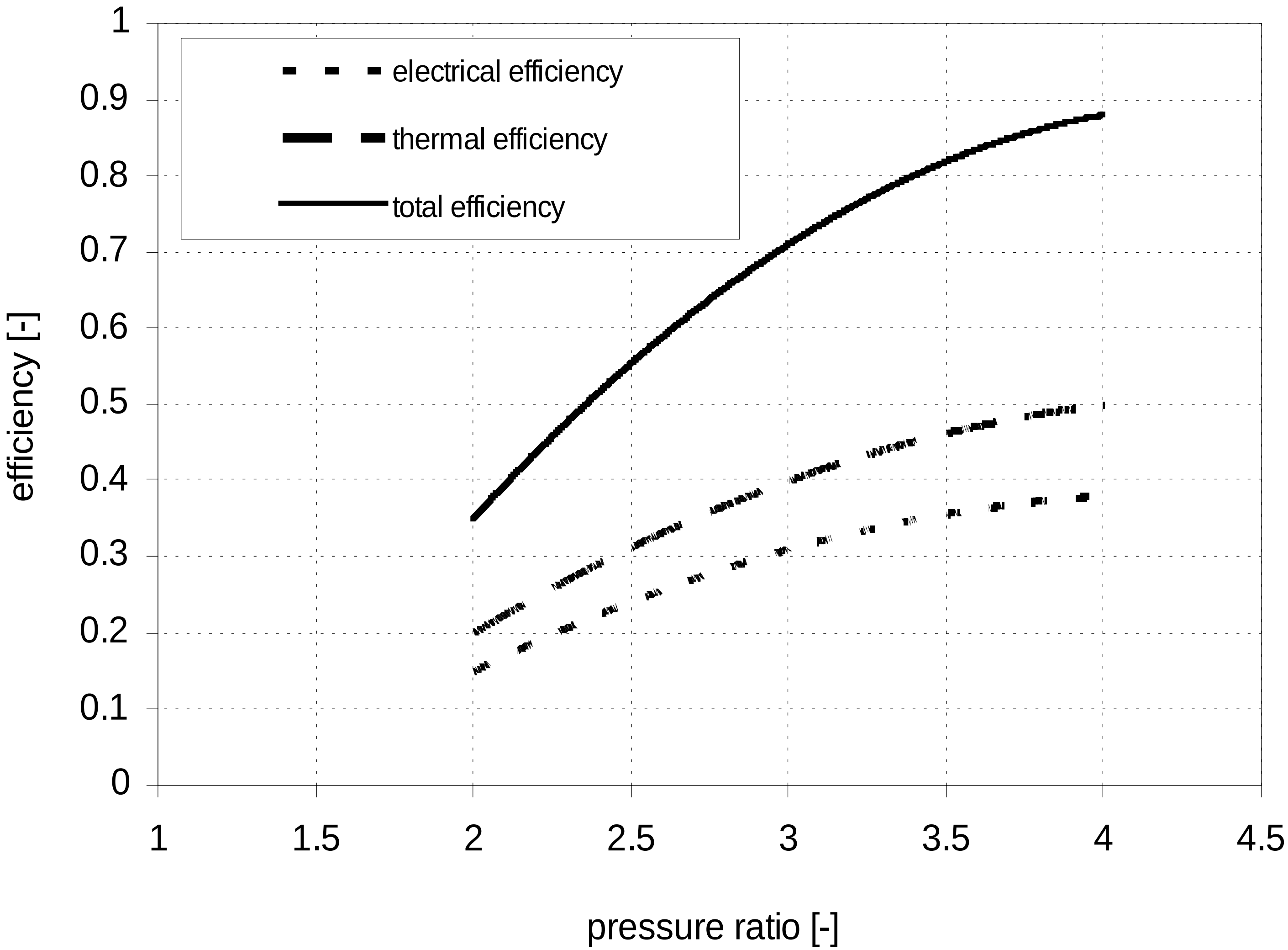
•The cogeneration system based on a gas turbine operates at steady state;
•ideal gas mixture principles apply for the air and combustion products;
•fuel is natural gas taken as ideal gas;
•the fuel combustion in combustion chamber is complete;

Key tools applied in modelling include:
energy balances, mass balances where necessary and composition of reacting elements. These tools will be expressed using a set of governing equations.

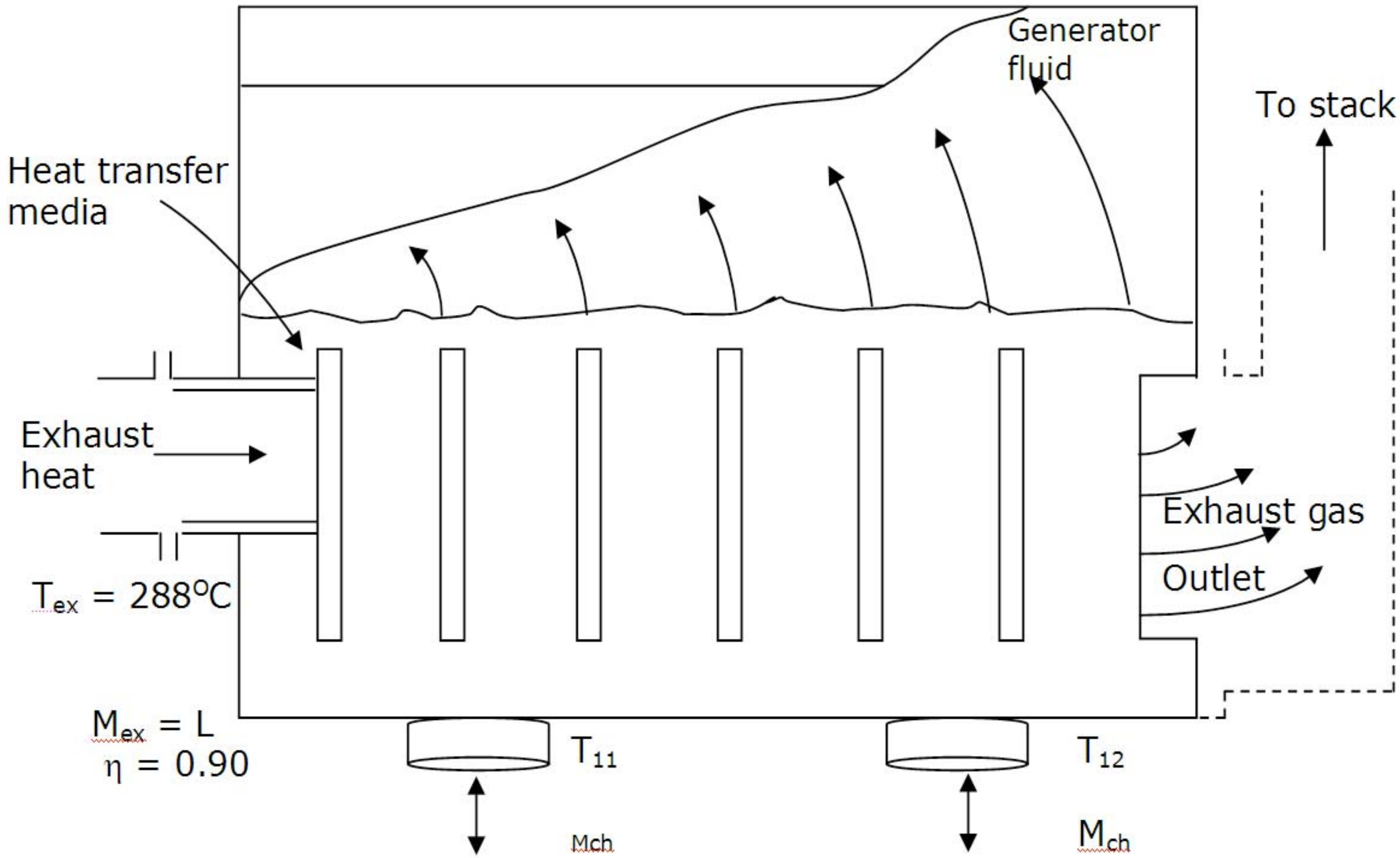
Schematic of the cogeneration micro-gas turbine



Example of sensitivity analysis
Influence of pressure ratio on MGT performance



Schematic of the recuperator used for the integrated absorption chiller



Exergy and thermoeconomic analysis

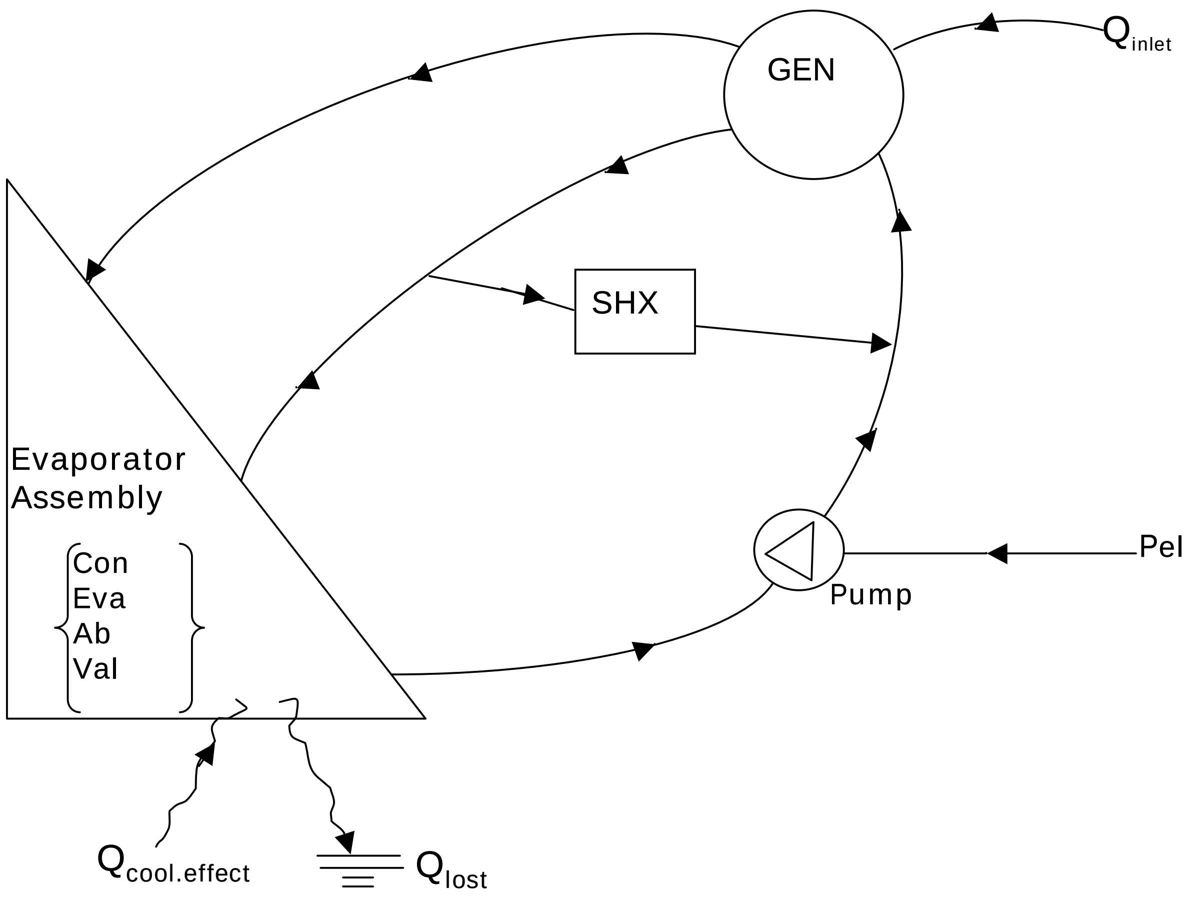
An exergy evaluation is necessary for the absorption cycle to:

- identify presence of irreversibility;
- determine available useful exergy; and
- quantify the exergy destroyed

Assumptions:

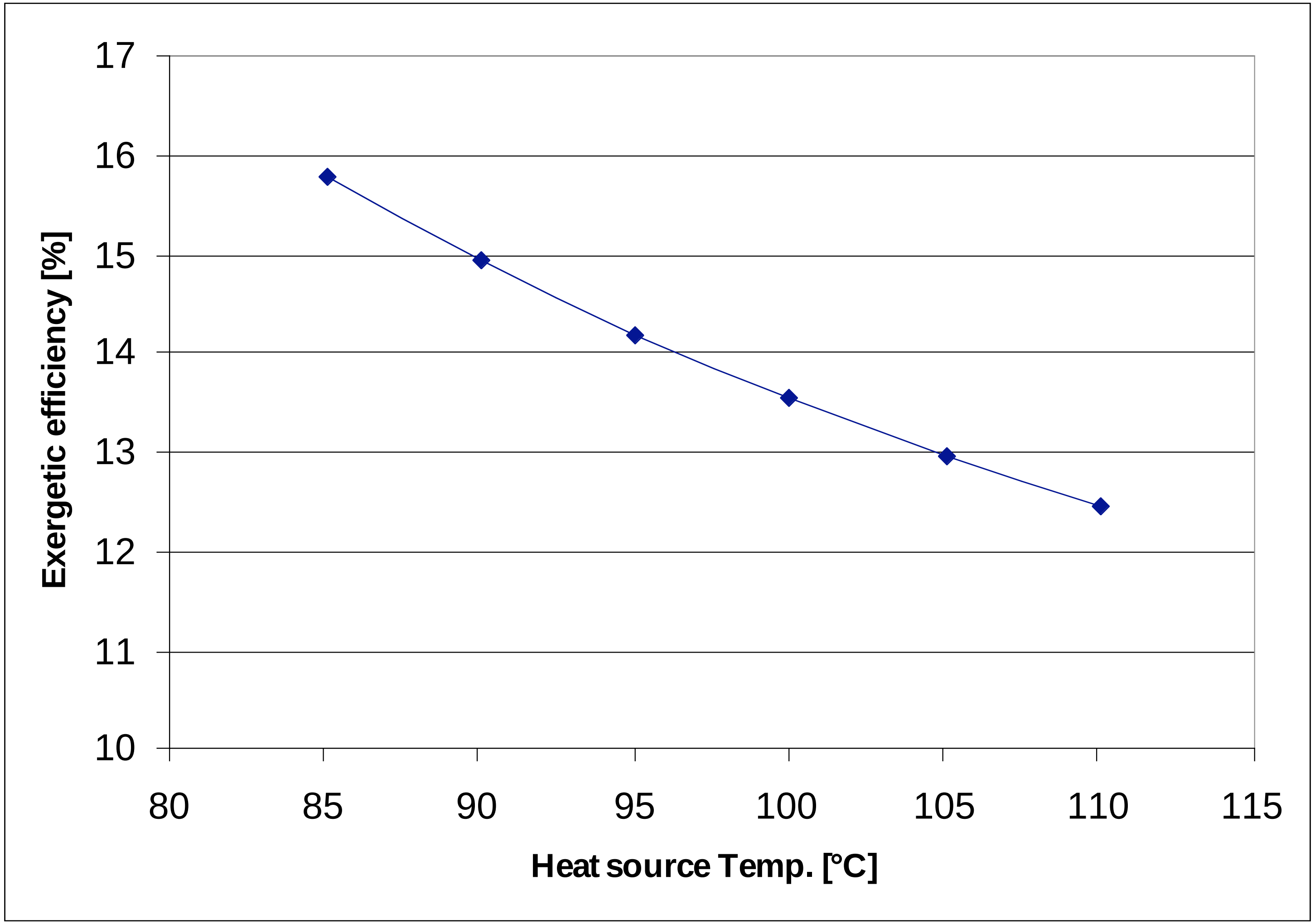
- the system flows under steady-state conditions;
- the reference environmental state point for system is T_0 = 25^0C and, P_0 =101.325KPa;

Exergy cost balancing schematic diagram



Example of sensitivity analysis

Influence of heat source temperature on Exergetic Efficiency



Conclusion

- The work has reduced knowledge gap on how to provide alternative energy technology for remote areas in Nigeria,
- contributed towards the domestication, both the technology of, and
- expertise in cogeneration operated absorption refrigeration in Nigeria.
- Throughout the literature survey presented, no example of previous work or existing functional system understudy is seen for Nigeria.
- Adoption of both cogeneration and absorption refrigeration technologies can be feasible and would benefit rural lifestyle and boost agricultural production.

Grazie a tutti per l’attenzione !