FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF MECHANICAL AND MECHTRONICS ENGINEERING

ENME 511
Power Laboratory

Laboratory Manual

2019

LAB MANUAL CONTENT

Lab Safety Instructions and Rules
Mechanical Engineering department

General Behavior

- Never work in the laboratory alone, always have another qualified person in the area do not use any equipment unless you are trained and approved as a user by your instructor or staff. Ask questions if you are unsure of how to operate something.
- Perform only those experiments authorized by the instructor. Never do anything in the laboratory that is not called for in the laboratory procedures or by your instructor. Carefully follow all instructions, both written and oral. Unauthorized experiments are prohibited.

- Don't eat, drink, or smoke, in the laboratory
- Please don’t yell, scream, or make any sudden loud noises that could startle others who are concentrating on their work.

- When you are done with your experiment or project, all components must be dismantled and returned to proper locations.
- When operating high noise machines put on ear protection, those are available in the lab and will be given by the instructor.

- Shoes must completely cover the foot. No sandals are allowed.
- Dress properly during all laboratory activities. Long hair, dangling jewelry, and loose or baggy clothing are a hazard in the laboratory. Long hair must be tied back and dangling jewelry and loose or baggy clothing must be secured.
- Keep aisles clear and maintain unobstructed access to all exits, fire extinguishers, electrical panels, and eyewashes.

First Aid & fire

- First aid equipment is available in the lab, ask your instructor about the nearest kit.
- Fire extinguisher are available in the lab, ask your instructor about the nearest one to your lab.

Poisons

- Certain liquids used in our apparatus, for example refrigerants, manometer fluids, and mercury, are poisonous or can give off poisonous vapors.
- Avoid contact with such liquids, clean up any that is spilled and perform operations such as the filling of manometer in well ventilated conditions.

Electricity

- Do not handle electrical equipment while wearing damp clothing (particularly wet shoes) or while skin surfaces are damp.
- Never bend or kink the power cord on an instrument, as this can crack the insulation, thereby introducing the danger of electrical shocks or burns.

- Know where the stop button, main switch or other device for stopping the apparatus is located

Machines and moving parts

- In order to avoid the possibility of injuries, it is important that the students be aware of their surroundings and pay attention to all instructions.
- Deal with caution with rotating machines, fans pumps compressors, motors etc. don't touch any of the rotating parts; shafts, or blades.
- Read and understand operation instructions before turning on the machines, do not turn machine till you instructed by the instructor or the technician.

High pressure cylinders

- Deal with caution with high pressure cylinders and systems.
- Turn such cylinders off after finishing the experiment.
- Close LPG cylinders safely after completing your experiment.

Hot surfaces and burns

- Do not touch hot surfaces; hot plates boilers, heating elements machines etc.

High flow streams

- When using compressed air, use only approved nozzles and never direct the air towards any person.
- Exercise care when working with or near hydraulically- or pneumatically-driven equipment.

EXPERIMENT No. (1)

EXPERIMENTAL HEAT PUMP AND AIR COOLER

<u>INTRODUCTION:</u>

It is desired to know how the apparatus may be used as a Heat pump (HP) at first, and second, when the direction of flow is reversed, the same apparatus is used as an Air cooler (AC).

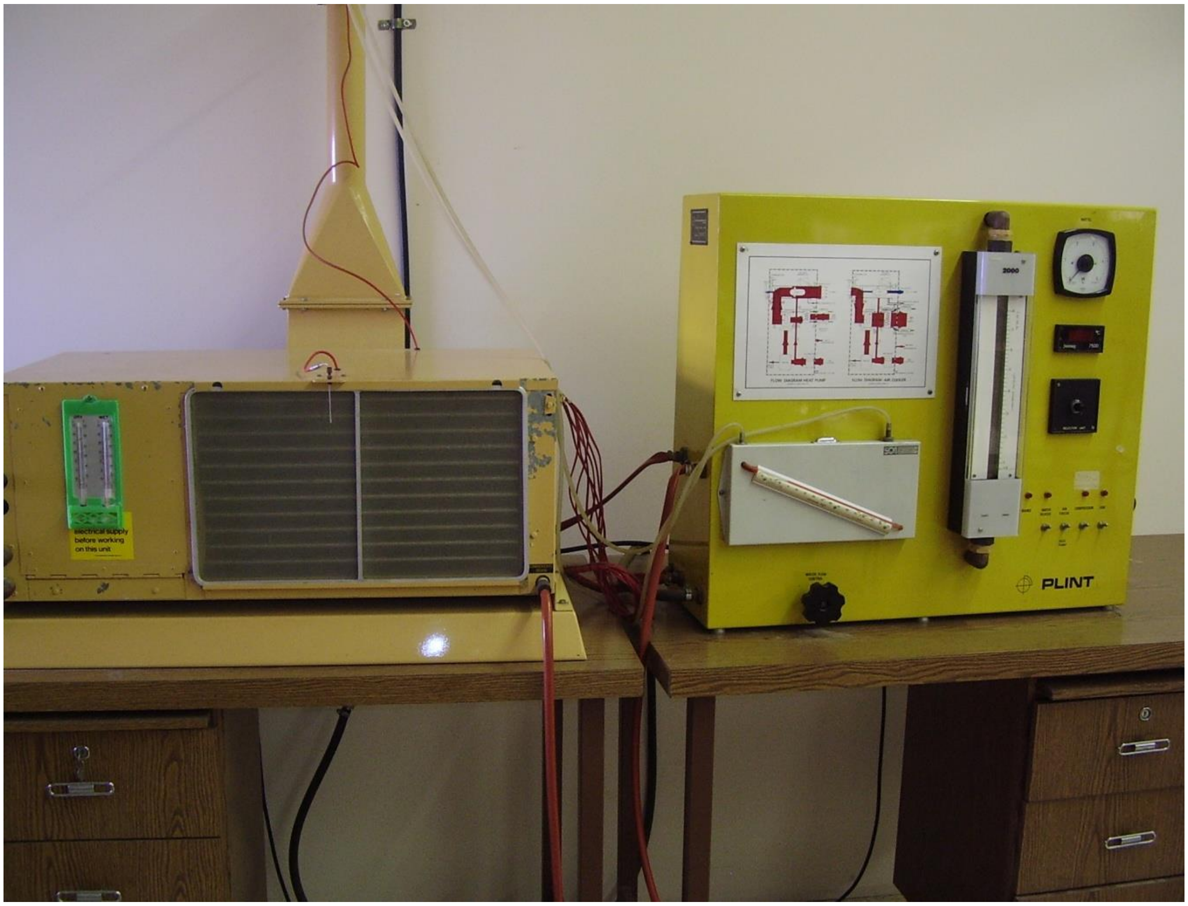


Figure (1) Experimental Heat Pump and Air Cooler

EXPERIMENTAL PROCEDURE :

1. Turn on the cooling water to give a flow of 4 l/min, ***Note*** : If the temperature of water is less than 10^{o}C and the apparatus is to operate as a (HP), the water heater must be switched on.
2. Select cooling or heating, switch on the compressor and fan. Take readings of temperature every 10 minutes until it stabilizes.
3. The wattmeter shows the total electrical input to both the fan and compressor, to measure the input to the fan alone, switch off the fan momentarily and read the power to the compressor then subtract this reading from the total reading.
4. The relative humidity of air entering the conditioner is measured by means of the sling hygrometer (Dry bulb / Wet bulb).

Experimental Results : Heat Pump

1. Record T_1 , T_2 ,.......,T_{10} ^{o}C , H_1 mm H_2O, E_c , E_F , P_a , Φ , m_2 and l.
2. Change water flow rate 6 times and repeat experiment.

CALCULATIONS :

m_3 = circulating water kg/s

ρ_w = from steam tables kg/m^3

P_a = from equation (1)

$$\frac{P_a}{\rho_a} = RT \qquad R = 287 \text{ for air} -----(1)$$

γ = from equation (2)

$$\gamma = \frac{\phi \rho_w}{\rho_a} ------(2)$$

V = from equation (3)

$$V = 0.3014\sqrt{\frac{H_1 T_2}{P_a}} ------(3)$$

m_1 = from equation (4)

$$m_1 = 0.00105\sqrt{\frac{H_1 P_a}{T_2}} ------(4)$$

c_p = for dry air = 1012 J/kg ^{o}C

h_v = from steam tables J/kg

c_w = specific heat of water = 4186.8 J/kg ^{o}C

Then,

$Q_1 = m_1\, c_p\, T_1$
$Q_2 = \gamma\, m_1\, h_v$
$Q_3 = m_1\, c_p\, T_2$
$Q_4 = (\gamma\, m_1 - m_2)\, h_v$
$Q_5 = m_2\, h_w$
$Q_6 = m_3\, T_3\, c_w$
$Q_7 = m_3\, T_4\, c_w$
Q_8 = Radiation and stray losses

Then the Steady Flow Energy Equation for the system is:

$$(Q_6 - Q_7) + (E_c + E_F) = (Q_3 + Q_4 + Q_5) - (Q_1 + Q_2) + Q_8 \text{ ----- } (5)$$

The coefficient of Performance, equation (6)

$$(CP_H)_E = \frac{(Q_3 + Q_4 + Q_5) - (Q_1 + Q_2)}{(E_c + E_F)} ------(6)$$

The corresponding Ideal value, equation (7)

$$(CP_H)_{max} = \frac{\frac{1}{2}(T_1 + T_2)}{\frac{1}{2}(T_1 + T_2) - \frac{1}{2}(T_3 + T_4)} ------(7)$$

The internal coefficient of performance, equation (8)

$$(CP_H)_I = \frac{(Q_3 + Q_4 + Q_5) - E_F - (Q_1 + Q_2)}{E_c} ------(8)$$

Compared with ideal, equation (9)

$$(CP_H)_{max} = \frac{T_{10}}{T_{10} - T_8} ------(9)$$

EXPERIMENATL RESULTS: AIR COOLER

1. Record T_1 , T_2 ,......., T_{10} , H_1 , E_c , E_F , P_a , Φ , m_2 and l.
2. Change water flow rate 6 times and repeat experiment.

CALCULATIONS:

m_3 = circulating water kg/s

ρ_w = from steam tables kg/m^3

ρ_a = from equation (1)

γ = from equation (2)

V = from equation (3)

m_1 = from equation (4)

From steam tables find:

h_v , h_w , Q_1 , Q_2 , Q_3 , Q_4 , Q_5 , Q_6 and Q_7.

The stray losses are in this case negative, representing heat gain from the surroundings.

Then the steady flow energy equation is read from equation (5).

The coefficient of performance, equation (10)

$$(CP_R)_E = \frac{(Q_1 + Q_2) - (Q_3 + Q_4 + Q_5)}{(E_C + E_F)} ------(10)$$

Compared with ideal value, equation (11)

$$(CP_R)_{max} = \frac{\frac{1}{2}(T_1 + T_2)}{\frac{1}{2}(T_3 + T_4) - \frac{1}{2}(T_1 + T_2)} ------(11)$$

The internal coefficient of performance, equation (12)

$$(CP_{PR})_I = \frac{(Q_1 + Q_2) + E_F - (Q_3 + Q_4 + Q_5)}{E_c} ------(12)$$

Compared with the ideal, equation (13)

$$(CP_R)_{max} = \frac{T_{10}}{T_8 - T_{10}} ------(13)$$

NOTATION:

Diameter of discharge duct	D_m = 0.073 m
Rate of flow of discharge air	V m^3/s
Rate of flow of circulating water	l l/hour
Barometric Pressure	P_a N/m^2
Density of air at discharge	ρ_a kg/m^3
Pitot tube velocity head	H_1 mm H_2O
Maximum velocity in discharge duct	U m/s
Mean velocity in discharge duct	U m/s

Temperatures ^oK

T_1	Air at inlet		
T_2	Air at discharge		
T_3	Circulating water at inlet		
T_4	Circulating water at discharge		
		HP	***AC***
T_5	Compressor	discharge	inlet
T_6	Compressor	inlet	discharge
T_7	Refrigerant-to-water heat exchanger	discharge	inlet
T_8	Refrigerant-to-water heat exchanger	inlet	discharge
T_9	Refrigerant-to-air heat exchanger	inlet	discharge
T_{10}	Refrigerant-to-air heat exchanger	discharge	inlet

Mass Flow rates

Dry air	m_1 kg/s
Condensate at discharge	m_2 kg/s
Circulating water	m_3 kg/s

Thermal Quantities

Specific heat of water	c_w J/kg ^oC
Specific heat of air at constant pressure	c_p J/kg ^oC
Specific enthalpy of water vapour	h_v J/kg
Specific enthalpy of condensate	h_w J/kg

Enthalpy Flow rates

Dry air entering conditioner	Q_1 J/s
Water vapour entering conditioner	Q_2 J/s
Dry air leaving conditioner	Q_3 J/s
Water vapour leaving conditioner	Q_4 J/s
Condensate	Q_5 J/s
Circulating water at inlet	Q_6 J/s
Circulating water at outlet	Q_7 J/s
Radiation and stray losses	Q_8 J/s

Electrical Input

Refrigerator compressor	E_c W
Fan	E_F W

Psychometric Data

Relative humidity at inlet	Φ
Density of saturated water vapour at inlet	ρ_w kg/m^3
Density of dry air at inlet	ρ_a kg/m^3
Specific humidity at inlet	γ

Ideal Heat Pump

Power input	W J/s
Input from cold source	q_2 J/s
Output to hot sink	q_1 J/s

CALCULATIONS :

1. Find the basic characteristics of HP and AC, for example [Power vs Time] i.e. warm up process.
2. Find the energy balance for both the HP and AC.
3. Compare the performance of HP and AC at different temperatures.
4. Draw the thermodynamic refrigeration cycle.

Data Sheet

Transient, *Water flow rate =* ***4 L.P.M***

Air Pressure = (   ) mmH_2O

Time (min)	Water Flowrate (L.P.M)	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC	T_6 ºC	T_7 ºC	T_8 ºC	T_9 ºC	T_{10} ºC	Total Power (kW)	Compressor Power (kW)	Wet Bulb Temp.	Dry Bulb Temp.	Φ
0	4															
5	4															
10	4															
15	4															
20	4															
25	4															
30	4															
35	4															

Steady State,

Air Pressure = (   ) mmH_2O

Time (min)	**Water Flowrate (L.P.M)**	**T_1 ºC**	**T_2 ºC**	**T_3 ºC**	**T_4 ºC**	**T_5 ºC**	**T_6 ºC**	**T_7 ºC**	**T_8 ºC**	**T_9 ºC**	**T_{10} ºC**	**Total Power (kW)**	**Compressor Power (kW)**	**Wet Bulb Temp.**	**Dry Bulb Temp.**	**Φ**
	5															
	6															
	3															
	2															

EXPERIMENT No. (2)

CHARACTERISTICS OF AXIAL MACHINES

INTRODUCTION:

The universal Axial flow machines apparatus has been designed to enable students to study the performance of an axial flow machine of variable blade angle in both the pump and turbine modes of operation with water as the operational fluid. The design of the apparatus is such that the visual effects of blade cavitation could easily be seen.
In axial flow machines, the flow is in the direction of the axis of rotation. The given apparatus can be operated either as an axial flow pump or an axial flow turbine . This depends upon the machine gives power to the fluid *(PUMP)* or the fluid gives power to the machine *(TURBINE)* .

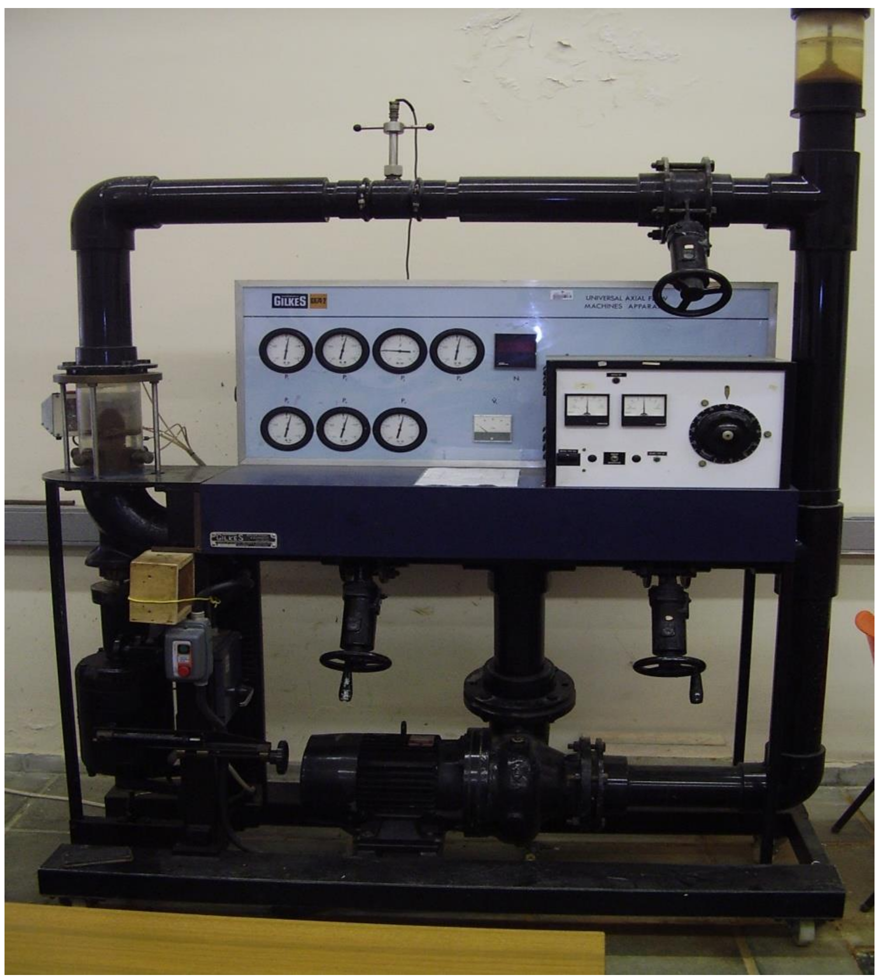


Figure (1) Axial Pump

Pump operation:

The blade angle (α) and diffuser blade angle (β) can be changed as follows:

ROTOR ANGLE (α) degrees	***DIFFUSERANGLE (β) degrees***
10	+10, -10
30	+10, -10

Set α = 10 and β = +10

1. For operating as a pump, open valves 1, 2 and 3.

2. Operate the pump at a certain speed (N_1) rpm. Record Q, the various pressures, the Torque force (After balancing the dynamometer) .

3. Change the discharge by valve (1) and return the speed to the same N_1, record pressures, Q, Torque.

4. Repeat the previous procedure two times changing N.

5. Change angles as given below

α	β
10	+10, -10
30	+10, -10

Pump efficiency :

$$\mu_p = \frac{\rho g Q \Delta H}{T.\omega}$$

Torque T = 0.178 F N.m

$\Delta H = 10.194(P_7 - P_1)(mH_2O)$ Where P_7 & P_1 are in bars

Angular velocity $\omega = 2\pi N / 60$ rad/s.

- Draw the characteristics curve for the pump (ΔH - Q), plot efficiency versus Q on the same graph.
- Comment on the effect of α , β on characteristics curves.

Pressures:

P_1: Pump inlet / Turbine outlet.
P_2: Pump nose / Turbine exit.
P_3: Blade inlet (Pump) / Blade outlet (Turbine).
P_4: Blade center.
P_5: Blade outlet (Pump)/ Blade inlet (Turbine).
P_6: Diffuser inlet (Pump) / Guide vanes (Turbine).
P_7: Pump outlet / Turbine inlet.

<u>Data Sheet</u>

Axial Pump

Rotor Angle = 10, diffuser Angle = -10
N=2500

P1 (bar)	P7 (bar)	Q (L.P.S)	Volt (V)	Current (A)	F (N)

Rotor Angle = 20, diffuser Angle = -10
N=2500

P1 (bar)	P7 (bar)	Q (L.P.S)	Volt (V)	Current (A)	F (N)

Rotor Angle = 30, diffuser Angle = -10
N=2500

P1 (bar)	P7 (bar)	Q (L.P.S)	Volt (V)	Current (A)	F (N)

Rotor Angle = 10, diffuser Angle = +10
N=2500

P1 (bar)	P7 (bar)	Q (L.P.S)	Volt (V)	Current (A)	F (N)

Rotor Angle = 20, diffuser Angle = +10
N=2500

P1 (bar)	P7 (bar)	Q (L.P.S)	Volt (V)	Current (A)	F (N)

Rotor Angle = 30, diffuser Angle = +10
N=2500

P1 (bar)	P7 (bar)	Q (L.P.S)	Volt (V)	Current (A)	F (N)

EXPERIMENT No. (3)

DIESEL ENGINE

Figure (1) Diesel Engine

1. ***TORQUE AND POWER - SPEED CHARACTERISTICS CURVES***

Particularly in the case of automobile spark-ignition engines , the full-throttle (maximum power) torque-speed curve is of interest, as showing one of the most important characteristics of the engine in terms of vehicle performance, and illustrating the effect of volumetric efficiency (breathing capacity) on output .

To obtain the characteristic, the engine should be warmed up at full throttle opening and at some speed around the midpoint of its range.

Adjust mixture strength and where applicable timing, to give maximum torque. Increase dynamometer loading to reduce engine speed to the lowest value at which the engine will run smoothly. Where applicable adjust spring balance level to bring torque arm pointer into line with the fixed pointer on dynamometer casing and record speed, preferably by counter and stop watch. While the speed is being measured make several observations of spring balance reading and record average value.

The rate of doing work, or power, is measured in Watts (Newton-meters per second) or kilowatts, and is the product of torque and angular velocity.

$$P = \frac{1}{1000} . \frac{2\pi\ n}{60} . T - - - - - - - (1)$$

Where:

P = Power, kilowatts

n = revolutions per minute

Plot Torque and power versus speed. Comment on power curve.

T vs s

P vs s

2. ***MEASUREMENT OF AIR FUEL RATIO AND TEMPERATURES***

The Fuel gauge, consists of a glass tube containing four knife-edged spacers. The spacers are so positioned as to contain an accurately calibrated volume of fuel between them.

The test procedure is first to fill the fuel gauge to a level above the top spacer by opening the air vent cock on the top of the gauge. The valve connecting the gauge to the fuel supply is then closed, when the engine draws fuel from the gauge. As the fuel level passes the top spacer a stop watch is set in motion and, with an electrical dynamometer, the revolution counter is engaged. During the fuel consumption the dynamometer spring balance reading is observed and the average value recorded. The measurement may be terminated when the fuel passes any one of the lower spacers, but the duration of the test should not be less than about 50 secs. As the fuel passes the lower spacer the stop watch is arrested and the counter disengaged. Record air flow, cooling water flow rate, inlet and outlet temperatures as well as exhaust gases temperature.

On completion of the test be sure to re-open the valve connecting the fuel gauge with the fuel tank and to close the vent cock, otherwise the engine will run out of fuel.

Fuel consumption is calculated as follows:

$$V = \frac{3600\ V_G}{t} \text{ ------------- (2)}$$

Where:

V_G = calibrated volume of fuel gauge, liters

t = time to consume calibrated volume, secs.

V = fuel consumption, liters/hour

Calculate air fuel ratio (A/F). Plot A/F versus speed.
Plot on one diagram Inlet and Outlet water temperatures, exhaust temperature versus speed.

3. <u>SPECIFIC FUEL CONSUMPTION AND POWER OUTPUT</u>

An important characteristic of an internal combustion engine is the specific fuel consumption since this gives a measure of the thermal efficiency of the engine. It is defined as follows :

$$v = V / P \text{ ------------ (3)}$$

v = specific fuel consumption l/kW.h

Plot specific fuel consumption (s.f.c) versus speed.

Engine performance is usually reported in terms of the ***brake mean effective pressure*** (b.m.e.p.). This is the calculated mean pressure that would have to act upon the pistons during each working stroke to achieve the observed power output if there were no mechanical losses.

The power output of the engine, in terms of the b.m.e.p. is given by:

$$P = \frac{\bar{p} n V_s}{6 \times 10^4 \times K_2} \text{ -------- (4)}$$

where :

$\bar{p}$ = b.m.e.p., kN/m^2

V_S = swept volume of engine, $liter^3$

K_2 = 2

The swept volume is given by:

$$V_s = \frac{\pi d^2 sN}{4 \times 10^6} --------(5)$$

Where: Engine Type Bore 4.108

d = cylinder diameter, mm: 79.735 mm (3.125 in)
s = piston stroke, mm: 88.9 mm (3.5 in)
N = number of cylinders: 4

Rearranging equation (4):

$$\bar{p} = \frac{6 \times 10^4 K_2 P}{nV_s} --------(6)$$

Plot b.m.e.p versus speed.

Data Sheet

	Motor Speed	Torque	Time	Temp. from Engine	Temp. To Engine	Water Flow	Exhaust Temp.	Air Flow
Stage 1	RPM	N.m	sec.	T_1 °C	T_2 °C	L/m	T_{exh} °C	mm H_2O
Throttle 15%								
Stage 2								
Throttle 20%								
Stage 3								
Throttle 40%								
Stage 4								
Throttle 50%								

Fuel Consumption : 50 mL
Orifice Dia. : 59.82 mm

EXPERIMENT No. (4)

AIR CONDITIONING UNIT

Introduction:

Air conditioning unit ETG20 from GUNT simulates an actual AC unit. It can provide , conditioned air at preset conditions of temperature and relative humidity. The unit as shown in figure 1 contains the main components of a commercial AC unit: rectangular ducts that include a filters, fan, cooling coil, heating coil, humidifier, air registers, grills, and dampers.

The unit can be operated manually or on automatic mode; in the automatic mode the operator specifies the output air temperature and relative humidity, then the unit will run such that those conditions are reached. In the manual mode the, operator can select the fan speed, heating rate (kW), steam humidifying setting then the air temperature and humidity at inlet and exit will be read from the control screen.

Objectives:

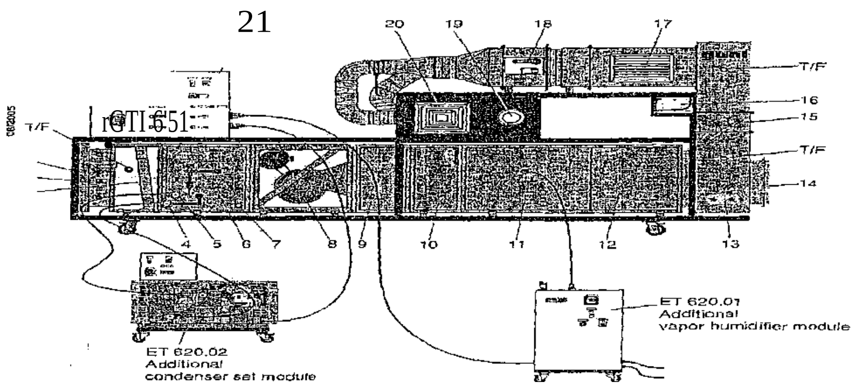
The AC unit is a real size system, the main objective is to train student on the operation of the AC unit.

Specific objectives of these experiments are:

- Identify components of an AC system
- To see types of air grilles and distribution systems.
- Operate an AC system
- Control of an AC system
- Manually operate of an AC system
- Use the Psychometric chart and find air properties
- Understand basic air conditioning processes
- Carry out AC processes and present on Psychometric chart
- Perform heating and cooling calculations
- Perform steam addition and condensation calculations
- Experience the control of air flow and distribution in an AC system.

System description

Figure 1 shows schematic of the AC unit and the main parts of the unit. It is important for the student to become familiar with all the unit components and parts before running the experiments. Check the location of temperature and pressure sensors.

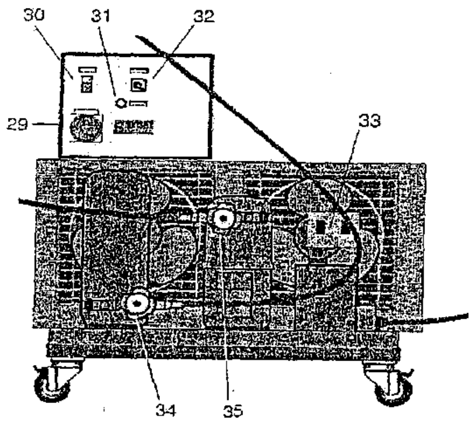


Overall view consisting of ET620 with additional elements ET620.01 and ET620.02

1	Weather protection grtlle	12	Inspection flap
2	Louvered flaps	13	Inspection cover
3	Filter	14	Connection flange for an external system
4	Refrigerant entry port	15	Shut-off flap
5	Refrigerant *exit* port	16	Inclined lube manometer
6	Cooling section (evaporator)	17	Ventilation grille
7	Condensate drain	18	Fire damper
8	Fan	19	Disk valve
9	Flow distributor	20	Ceiling air outlet
10	Heating section	21	Switch cabinet
11	Humidification section	T/F	Openings for combined sensors Temperature/Humidity

Figure 1

Figure 2 shows the vapor compression refrigeration unit which provides the cooling coil with the cooling effect. Figure 3 shows the main control board with read outs and selection knobs and light signals.



29 Main switch
30 On/off switch
31 Indicators
32 Manual/Auto changeover switch
33 Overpressure switch
34 Refrigerant return flow, vacuum side
35 Refrigerant outlet, high pressure side

Fig. 2.2 ET620.02

Figure 2

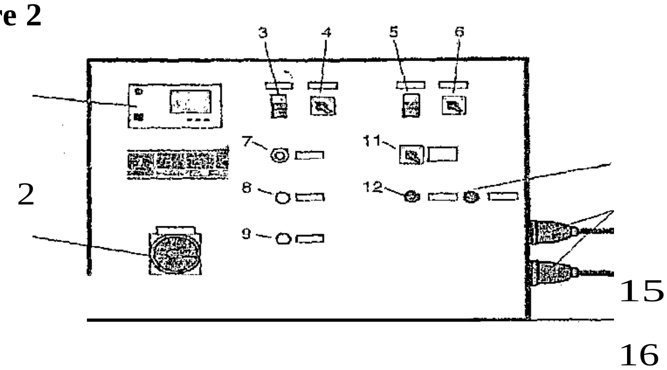
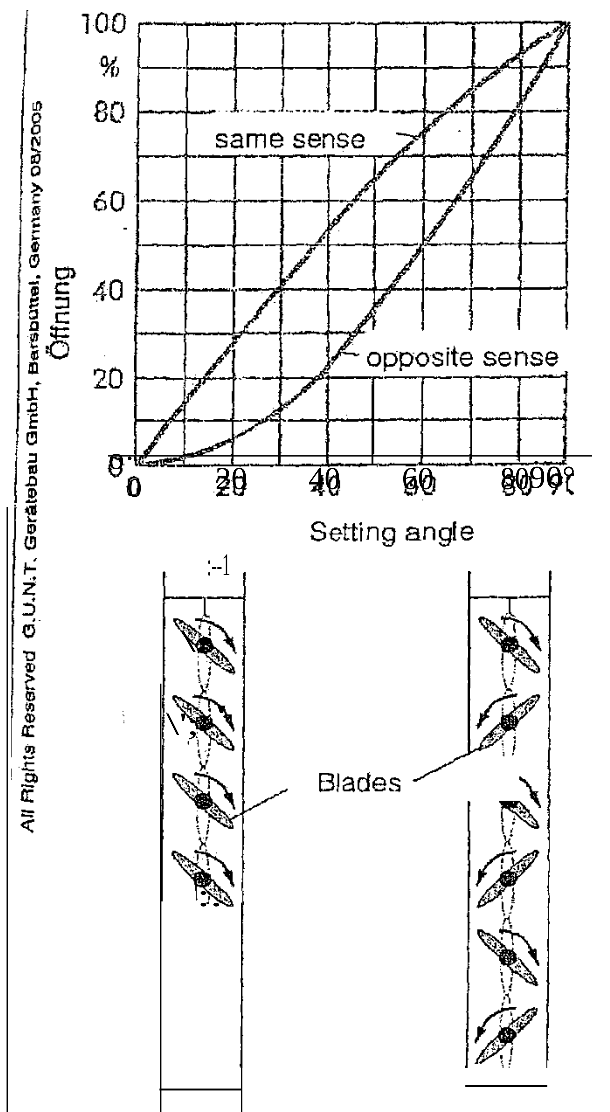


Figure 3

1 Main Switch
2 Controller
3 Fan push button
4 Fan operating mode changeover switch
5 Heater push button
6 Heater operating *mode* changeover switct1
7 Fan speed setting knob
8 Indicator lamp, minimum air flow achieved
9 Indicator lamp, humidifier in operation
10 Indicator lamp, condenser set in operation
11 Heater stage selection switch
12 Warning lamp, filter clogged
13 Warning lamp, STW
14 Warning lamp, STB
15 Wal'riing lamp, Fire damper
16 Electrical connections for ET620.01 and ET620.02

Air flow through the unit could be controlled through the louvered flaps at the duct inlet. Figure 4 shows the setting angle and the corresponding opening percent of the air inlet.



same sense opposite sense

Fig, 2.4 Opening characteristics of Louvered flaps

Figure 4

Filter function is to filter out and trap solid and gaseous contaminants in the air. How do you decide if the filter needs to be cleaned or changed (filter is clogged?)?

Fan

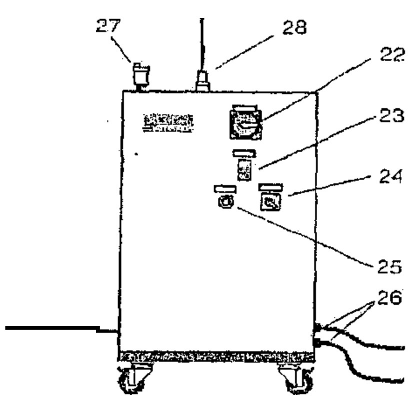
Air is circulated through the unit by a draft fan, the fan is variable speed, in the manual mode the setting can be selected, in the automatic mode fan % will be shown in the control screen.

Cooling section: cooling is achieved by the refrigerant that runs in the heat exchanger.(evaporator) of the vapor compression refrigeration unit. The used refrigerant is R404a. Condensation can occur if the air is cooled below the dew point? How would you find the dew point of the air drawn into the AC unit?

Heating section: Electrical heaters are used to provide the heating. In the manual mode the heating rate can be selected (off, 5kW, lOkW, 15 kW, and 20kW). Unit is provided with a safety temperature feature that turns of the heating coil once the air temperature reaches 75 °C.

Humidification section

Steam is provided by the humidifier unit to increase the humidity of the _air. Percent of humidifier can be set in the manual mode, see figure 5.



22 Main switch
23 On/off switch
24 Manual/Auto changeover switch
25 Adjusting knob 0...100%
26 Water inlet and water outlet
27 Automatic bleed valve
28 Spigot for vapor disct1arge

Fig. 2.3 ETE\20.01

Figure 5

Grills

Unit is provided with wall grills, ceiling grills and disk valve to provide the room with the conditioned air, see figure 1.

Manometer

An inclined manometer can measure the pressure difference between the selected points in the duct. Pressure difference may result from pressure losses and friction in the various equipments or as air flows in the duct.

Operation & Control

The systems are operated and monitored using the display on the PLC. The process information recorded by the PLC can be called up in the menu structure. ·

The unit can be operated in either manual or automatic modes, the automatic mode is the normal mode of operation, in which all control and regulations runs automatically based on the specified parameters (for example temperature and relative humidity) . All safety features are active.

Manual operating mode: In this case it is possible to influence set point, block of release individual switching and to monitor system status. Manual operation mode should only be run by trained personnel. It is essential to ensure that the associated vanes, valves are open before running the unit.
You can switch from automatic to manual using the switches in the main controller board.

Main controller display

Main menu of the PLC screen include the following functions, selecting the entry and pressing enter key takes you to the next menu.

- Warning alarm
- Setpoint temperature
- Setpoint humidity
- Switch
- Control parameters
- Limit values
- Heater level
- Humidifier
- Language

Warning alarm: (no alarm, filter blocked, insufficient flow rate, safety temperature monitor, safety temperature limiter).

Setpoint temperature: you can set the temperature of the air in the automatic mode. Adjust the set temperature and then press the Enter key (*), When the set temperature is flashing you can use the ? and ? keys to increase or decrease the set temperature. Press the Enter key to confirm the new v lue.

Setpoint humidity: relative humidity percent is set here.

Switch: the modes and status of the chiller, fan, heater and humidifier can be set here.

Chiller: auto, off, on.

Fan: auto, off, on.

Heater: switched on or off. For the heater on you can select one of the four levels L1= 5kW, L2 = 10 kW, L3 = 15 kW, L4 = 20 kW.

Humidifier: Auto either upper limit or lower limit, or manual mode select (O– 100 %).

Control parameters: to be set by technician.

Limit values:

Supply max air temperature

Supply min air temperature

Humidity max for inlet

Air temp. Max: maximum ambient air temperature

Air temp. Min: minimum ambient air temperature.

Heater level: heater level currently actuated is displayed here.

Humidifier: Power currently demanded from humidifier is displayed here.

Language: English, German, Spanish or French. i

Shutdown

Vapor humidifier:

Switch off the vapor humidifier

Switch off the main switch

Shut off the water supply

Condenser set

Switch off the condenser set
Switch off the main switch

Air conditioner
Switch off the heater
Set the fan speed control knob on zero
Switch off the main switch

Theoretical Considerations

Air is considered as a mixture of dry air plus water vapor, properties of this Air-water- vapor mixture is presented in the psychometric chart. As shown in the chart the following properties are included: dry bulb temperature of simply temperature, wet bulb temperature, specific humidity, relative humidity, specific volume, and enthalpy.

Air conditioning processes can be represented in the chart, main processes include: sensible heating or cooling, humidification and dehumidification at constant dry bulb temperature, heating with humidification, and cooling with dehumidification.

Air volume flow rate can be computed from manometer readings (pressure drops) based on Bernoulli's equation as

$$V = \sqrt{2Pv}/\rho$$

Where P_v is the velocity pressure (difference between total and static pressures. The air density is calculated using ideal gas equation ($p = P/RT$ P is the barometric pressure).

If the pitot-tube is located in the center of the duct then the average velocity is 0.9 times the velocity as measured by the pitot-tube.
Airflow = velocity x duct cross section.

Dry air mass flow rate is the air volume rate divided by the specific volume of air as given in the psychometric chart.

Heat transfer across the coil (heating or cooling loads of coil) is given as

$$Q = m_{dry\ air} * (h_{out} - h_{in})$$

Where $m_{dry\ air}$ the mass flow rate of dry air, h_{out} is the air enthalpy after the coil and h_{in} the air enthalpy before the coil.

Amount of condensed or added water vapor can be calculated as, $m_{water} = (\omega_2 - \omega_1) * m_{dryair}$
if $\omega_2 > \omega_1$ vapor is added, while if $\omega_2 < \omega_1$ then vapor has condensed.

Note that the enthalpy of air mixture is based on, $h = h_{air} + \omega h_{vapor}$

$h_{air} = Cp\ T$, while h_{vapor} is taken as the saturated vapor enthalpy h_g

Experimental part:
1) Air conditioning processes

In this part the AC unit to be operated on the manual mode under the supervision of the lab technician. In this part you carry out the processes as required by the instructor, you record all the readings inlet and outlet air temperature and relative humidity, manometer reading, fan speed etc.....

The AC processes include the following:

a. Sensible heating

Cooling coil is off, heater at 5 kW, humidifier is off.
Operate the unit for about one hour or until steady state is reached.

I) Describe the air conditioning process.
2) Plot your results as temperature and relative humidity at inlet and exit.
3) Locate inlet and exit conditions at steady state on the psychometric chart and the heating process.
4) Find all air properties from the chart (wet bulb temperature, specific humidity, enthalpy, specific volume).
5) Calculate per kg. dry air the heat added to the air, estimate the air velocity from such data, and compare it with the measure values from the manometer.

b. Sensible cooling

Heater is off, humidifier is off, for full opening of air inlet flaps; operate the AC system for 80 minutes or until steady state is reached, recording inlet, exit temperatures, and humidity every 5 minutes.

1) Note the transient behavior of the system, by plotting above variables versus time.
2) Explain the trends of relative humidity at inlet and exit.
3) Show inlet and exit states on the chart, then find all properties (wet bulb temperature, specific humidity, enthalpy, specific volume).
4) Calculate the air velocity and volume and mass flow rates from manometer readings.
5) Calculate the cooling per kg of dry air, plot cooling load versus time.
6) At steady state show process on the chart and compare it with expected one, explain the difference.

c. Constant temperature humidification

Cooler is off, heater is off, air flow at full setting, humidifier is on at 30%, then record inlet and exit conditions for 80 minutes or until reaching steady state.

1) Plot your results versus time, comment on the curves.
2) Locate inlet and exit points on the psychometric chart and find value of all other properties and present in a table (for time greater than 60 minutes).
3) Show processes on the psychometric chart, describe the process.
4) Calculate the amount of added vapor per kg of air.

d. Heating with Humidification

Cooler is off, full air flow rate, heater rating 5kW, for humidifier selections at 20% record all values for air inlet and exit. Operate for 1 hour

1) From the psychometric chart find value of all properties and present in table.
2) Show all conditioning processes on the chart.
3) Calculate per kg of dry air heat added to air and vapor added to air.

e. Cooling with dehumidification

Heater is off, humidifier is off, air flow at full rate, and cooling is on, then operate the AC unit recording inlet and exit conditions (every 5 minutes) till vapor condensate flows out of the system.

1) Show inlet and exit states on the chart and find value of all properties. Show processes on the chart.
2) What is the dew point of the air, does it agree with the experimental results?
3) Calculate the amount of condensed vapor.

e. Dehumidification and heating

Operate the AC unit manually from inlet air conditions to achieve comfort conditions of 50% relative humidity and dry air bulb temperature of 20 °C.

1) On the psychometric chart locate the inlet and exit conditions.
2) Discus you procedure with instructor before carrying it out.
3) Record all settings and data during experiment.
4) Suggest another approach to achieve the same comfort conditions.

2) Effect of air flow

Air flow rate through the system can be changed by either changing the louvered flaps opening or by changing the fan speed. When operated on the auto mode you cannot control the fan speed it will be set by the PLC.

1) Repeat run as specified by your instructor using three different louvered flaps openings.
2) Read manometer and calculate air velocity then volume (in CFM) and mass flow rates.
3) Find air properties from chart at inlet and exit,
4) Carry out the calculations for the coils.
5) Show the effect of air flow rate on the air conditioning process by plotting cooling loads, specific humidity versus air flow rate.

Data Sheet

Time (min)	T_1	F_1	T_2	F_2	Pressure
0					
5					
10					
15					
20					
25					
30					

EXPERIMENT No. (5)

PELTON TURBINE TEST

INTRODUCTION :

Turbines are generally classified either as impulsive turbines or as reaction turbines. The Pelton turbine (wheel) is an impulse turbine in that the conversion of the pressure head of the fluid into kinetic energy takes place entirely in the stationary nozzle and the role of the runner is solely to convert this kinetic energy into mechanical work. It consists basically of three components, an inlet nozzle, an impeller and casing.

The water leaves the nozzle at high velocity and strikes the buckets which themselves move in the same direction. The buckets are shaped such that the direction of the fluid`s relative motion is turned through almost $180^{o}$. The small angle of drift ( $= 4^{o}$ to $7^{o}$) see Fig. 7.1 from the $180^{o}$ deflection is made to prevent a complete reflection of the water jet so that it would not hit the back of the next following bucket, and hence, prevents reducing it`s speed.

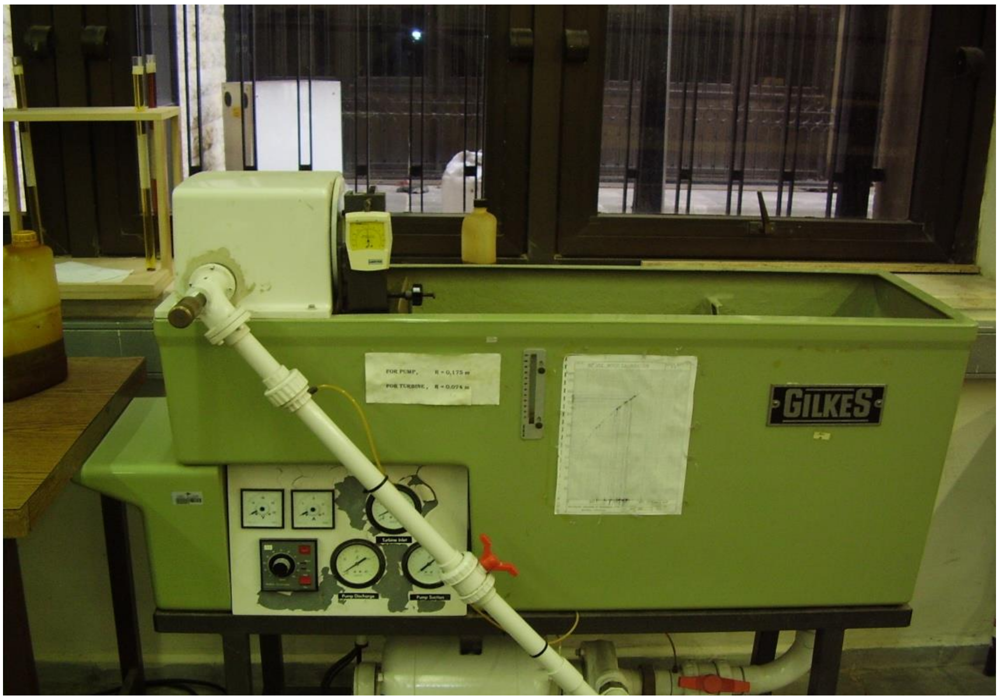


Figure (1) Pelton Turbine

THEORY :

Applying the momentum equation on the control volume, see Fig.7.2a (assuming steady flow conditions) the force reduces to

$$\mathbf{F} = \int_{CS} \rho \, \mathbf{v}\mathbf{v}.\mathrm{dA} \quad -------(7.1)$$

Torque is given by

$$\mathbf{T} = \mathbf{r} \times \mathbf{F} \quad -------(7.2)$$

therefore

$$\mathbf{T} = \int_{CS} \rho \, (\mathbf{r} \times \mathbf{v}) \, \mathbf{v}. \, \mathrm{dA} \quad -------(7.3)$$

where

$\int_{CS} \rho (\mathbf{r} \times \mathbf{v}) \mathbf{v}.\mathrm{dA}$	efflux of moment of momentum across the surface of the control volume [integrated over the whole surface area of the control volume].
$\mathbf{r}$	radial distance between the center of the runner to the point on the bucket where the water jet hits it.
$\mathbf{v}$	mean velocity of water jet.
dA	element of area.
ρ	mass density of fluid.

For a unit depth of the bucket the torque delivered by the machine is the integral of equation 7.3 which is the efflux of fluid through the control surfaces. Therefore

$$T = Q \, r \, [v_{t1} - v_{t2}] \quad ---------(7.4)$$

where (see Fig. 7.2b)

$v_{t1} = v_{r1} = v_1 - u$	tangential velocity of water jet relative to bucket at inlet.
$v_{t2} = v_{r2} \cos(180 - \theta) = - v_{r2} \cos \theta$	tangential relative velocity of the jet leaving the bucket
$u = \omega r$	velocity of bucket.
ω	angular velocity of the runner.

Substituting into equ. 7.4 yields

$$T = Q \, r \, v_r \, [1 - \cos \theta] \quad --------(7.5)$$

Input power to the turbine (mechanical power) is given by

$$P = T \, \omega = Q \, \omega \, r \, v_r \, [1 - \cos \theta] \quad --------(7.6)$$

The kinetic energy (maximum power) arriving at the wheel is

$$P_{max} = 1/2 \ Q \ v_1^2 \quad ----------(7.7)$$

The hydraulic efficiency of the turbine is given by

$$\eta_t = \frac{\text{Mech. Power}}{\text{Max. Power}} \times 100\% = \frac{T\omega}{\rho g Q H} \times 100\% \quad ---------(7.8)$$

Where H is the inlet turbine head.

APPARATUS :

The apparatus consists of a centrifugal pump that discharges water up to a nozzle at a rate that can be controlled by means of an adjusting knob.
The nozzle forms a water jet and hits the bucket of the runner.
The disc flywheel is connected to shaft of runner.

EXPERIMENTAL PROCEDURE :

In order to investigate the characteristic curves for the Pelton turbine, the head supplied by the centrifugal pump should be maintained const., either by use of the throttle valve or by variation in supply pump speed. The turbine load and speed are varied, using the brake assembly, for constant inlet head at various guide vane or spear settings. A suggested inlet head is 14m with guide vane or spear settings -
Full, 7/8, 3/4, 1/2, 3/8, 1/4 and 1/8 open and turbine speeds varied in increments of 250 rpm.
The reading of flow quantity, turbine speed and torque should be recorded at varying speeds. This should be repeated at alternative guide vane or spear settings.

QUESTIONS :

- Plot curves Q vs N rpm for constant turbine head H = 14m.
- On the same graph paper show the efficiency curves.

<u>Data Sheet</u>

Turbine Head = (   ) m

Throttle Opening	Water Flow rate		Force	Speed
	H (mm)	Q (L/m)	(N)	(RPM)
100%				
80%				
60%				
40%				
20%				

EXPERIEMNT No. (6)

TWO STAGE RECIPROCATING AIR COMPRESSOR

OBJECTIVE:

- Distinguish different types of compressors
- Examine parts of a reciprocating compressor.
- To measure air flow rate, pressure rise, power of a compressor
- Analyze p-v diagram of a single and a two stage compressor
- Measure volumetric, mechanical and isentropic efficiency of compressor
- Study the effect of compression ratio on performance
- First law analysis of compressor
- Operate a two stage compressor
- Study the effect of inter cooling on compressor performance
- Thermodynamic analysis of stored air (ideal gas and real gas).
- Study the effect of rpm on compressor performance.

APPARATUS DESCRIPTION:

The experimental set up includes a reciprocating two stage compressor with optional intercooler and a compressed air storage tank.

The system used to acquire the parameters of the compressed air as shown in Figure (1) consists of a series of sensors that transmit the operation data to an electronic interface. The PC and the software take these data and process them. The measured parameters include:

- The air humidity at the circuit inlet and outlet (atmospheric pressure)
- The pressure in the cylinder of the 1st and 2nd stage
- The air temperature at inlet and outlet of 1st and 2nd stage
- The compressor rpm
- An ammeter and a voltmeter to measure the power of the compressor.

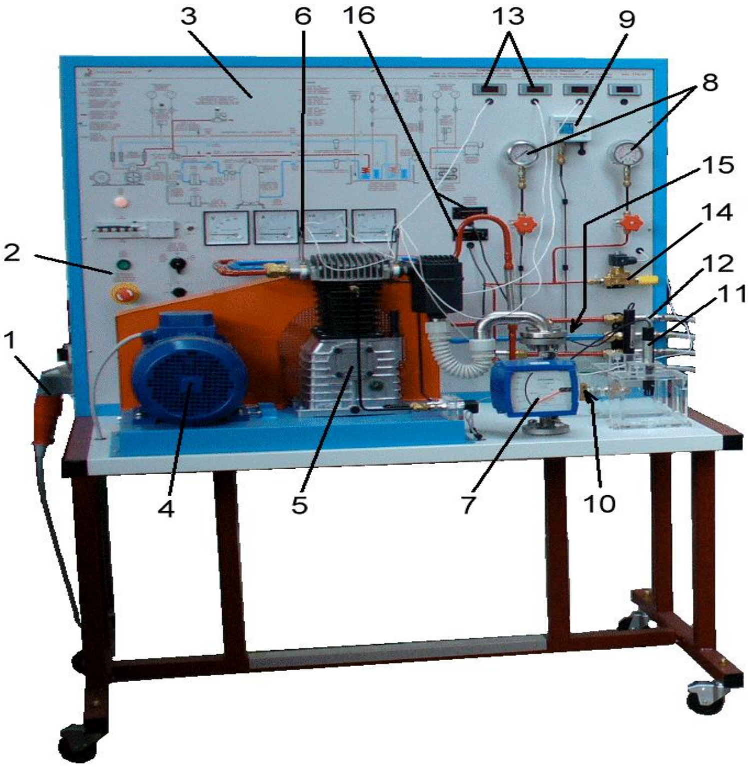


Figure (1) Two stage reciprocating compressor set up.

1. Power supply: 3-phase with neutral and ground
2. Electrical panel
3. Synoptic diagram in silk-screen aluminum
4. Electrical motor
5. 2-stage compressor
6. Temperature sensors
7. Flow sensor
8. Pressure gauges for high and medium pressure
9. Safety pressostat
10. Pressure regulator
11. Humidity sensors
12. Quick couplings for connection to opt. cooler
13. Digital thermometers
14. Electric safety valve
15. Mechanical safety valve
16. Hygrometers

The control panel includes switches and read outs as shown in Figure (2).

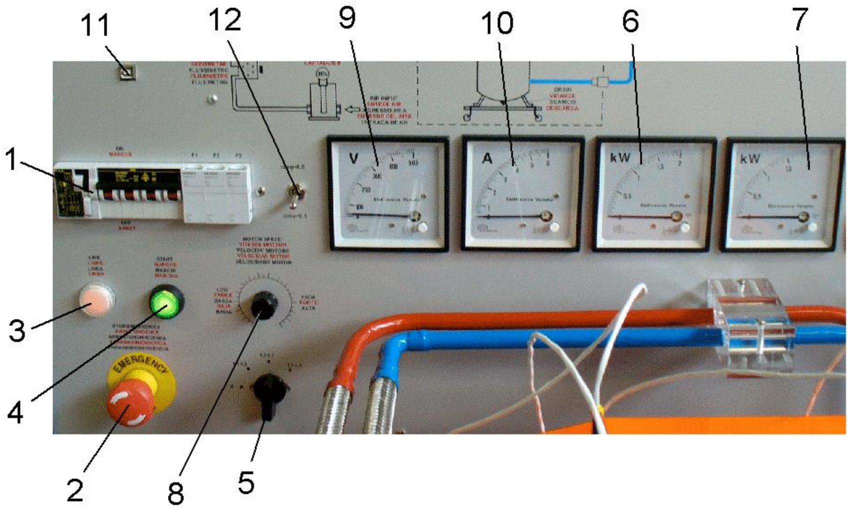


Figure (2) Control panel of system

1. Magneto-thermal switch, differential switch, fuses
2. Emergency push button
3. Line lamp
4. March button
5. Voltmetric selector
6. Wattmeter1
7. Wattmeter 2
8. Electric motor speed regulating potentiometer
9. Voltmeter
10. Ammeter
11. USB port
12. Voltmetric inverter of wattmeter no. 2

<u>Dimensions of each stage</u>

1^{st}. stage diameter = 90 mm
1^{st}. stage stroke = 65 mm
2^{st}. stage diameter = 50 mm
2^{nd} stage stroke = 65 mm

<u>Heat exchanger</u>

For each exchanger
Pipe diameter 12 mm
Pipe length 6.72 m
Surface area =0.255 m^2.

EXPERIMENTAL PROCEDURE:

The experiments that can be done with this equipment include;

- Study of a compressor.
- Measurement of the cycle pressure and temperature values.
- Determination of the aspired air mass.
- Determination of the specific heat absorbed by the air during the compression in the 1st and 2nd stage.
- Determination of the work done on the air mass.
- Determination of the exchanged heat.
- Calculation of the compressor volumetric efficiency.
- Calculation of the rated power of the 1st and 2nd stage.

Compressor speed, rpm

Through the electric motor speed regulating potentiometer you can modify at your best the motor rotation speed from zero value (when the potentiometer is completely rotated clockwise) to the maximum value (when the potentiometer is completely rotated counter-clockwise). Starting from the configuration corresponding to electric motor still, to increase the rotations of the motor you must rotate the control potentiometer clockwise.

Pressure regulation

The regulation of the system operating pressure is done using the pressure regulator set at the air outlet.

Operation with air tank

The compressor operation is controlled by the pressure switch which interrupts the motor supply when the air pressure in the tank reaches the maximum established value. When the pressure drops under the differential, it is necessary to press run button to start again.

Operation with cooler

If you connect the water tank to an external cooling circuit (shown in Figure 3) you can cool the compressed air both at the 1st and 2^{nd} compression stage. The gas cooling is accomplished by heat lost to the water tank from the copper tubing.

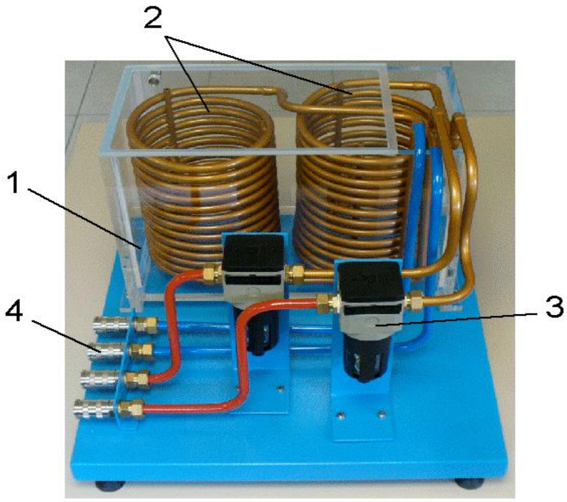


Figure (3) inter-cooling heat exchanger.

1. Tank,
2. Heat exchangers,
3. Automatic water drainage,
4. Quick pipe couplings for
   Connection to TTACM/EV

TTACM Software

The bench TTACM/EV application software is given from which the compressor system can be analyzed.

1. Running the program, the trainer's supervision window appears on the display. As shown in figure 4

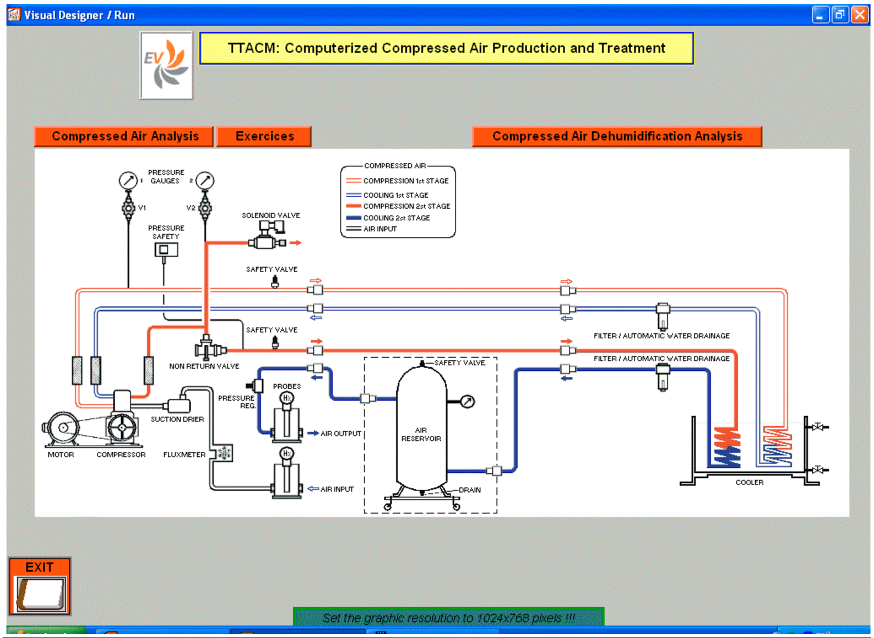


Figure (4) Supervision window.

2. Pressing button "**Compressed Air Analysis**" you enter the following display see figure 5, where you find the main components of the equipment, the temperature values, the pressures, the air relative humidity at the bench inlet and outlet, the value of the suction air flow, the number of turns of the compressor.

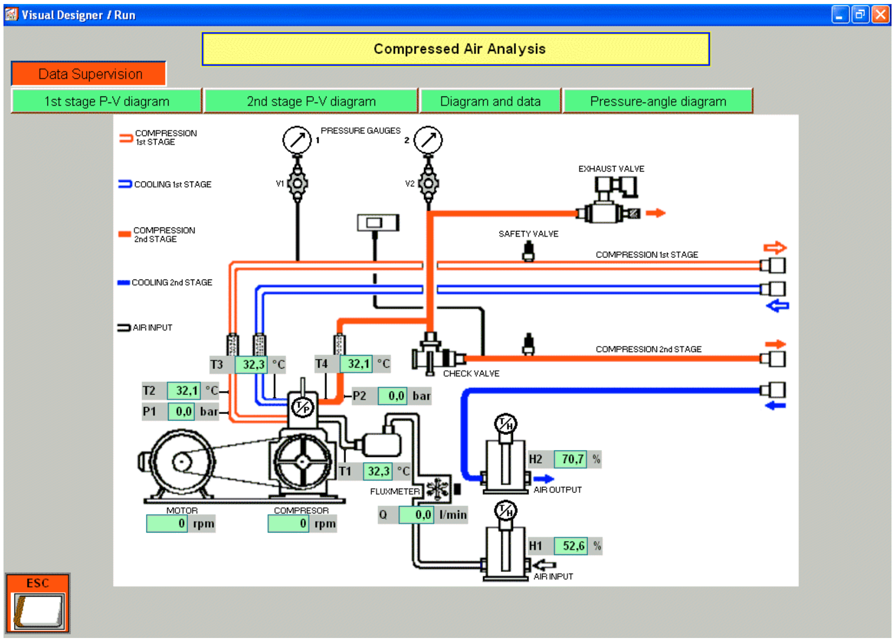


Figure (5) Compressor air analysis window.

On the top of the syn-optical diagram as shown in figure 5, there are four buttons which, when pressed with the mouse, allow to enter the thermodynamics elaborations, based on the values acquired by the probes.

Pressing the key "**1st stage P-V Diagram**", the pressure data corresponding to each position the first stage piston assumes during its run appear on the P-V diagram, figure 6.

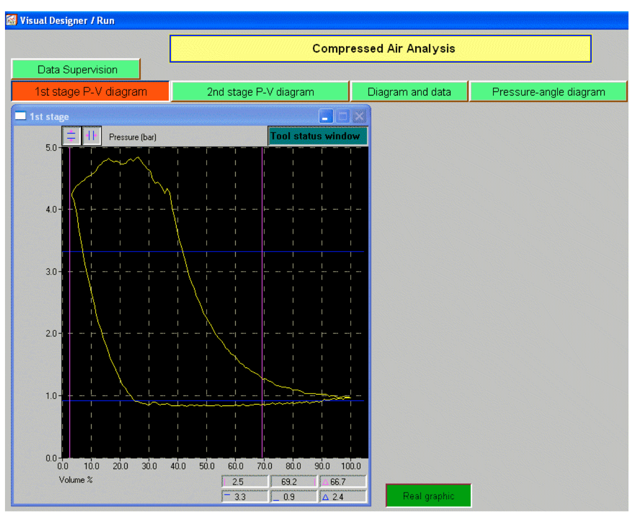


Figure (6) P-V diagram of 1st. Stage.

Pressing the key “**2nd stage P-V Diagram**”, the pressure data corresponding to each position of the second stage piston assumes during its run is drawn in the Pressure – Volume diagram, generating the real compression cycle. The same considerations developed for the first one are valid for this diagram.

Pressing the key “**Diagram and Data**” the two overlapped diagrams are represented, as shown in figure 6, whose forms, amplitudes and reciprocal position, are to be considered for evaluating the correct operation and the construction quality of the machine.

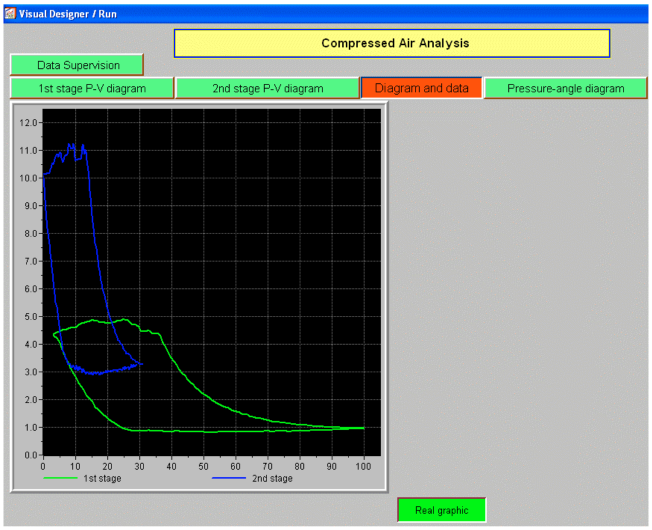


Figure (7) P-V diagram of two stages.

Pressing the key “**Pressure-Angle Diagram**” the pressure diagrams of the first and second states are represented, with reference to the lever.

<u>EXERCISES:</u>

From the main screen (figure 4), pressing the button “**Exercises**” you enter the exercises session (figure 8).

Selecting the option “**Practical**” you charge the real data detected by PC for doing the exercises. Note that you must enter via keyboard the room temperature and the atmospheric pressure.

Selecting the option “**Theatrical**” you can develop theoretical exercises based on the data written via keyboard.

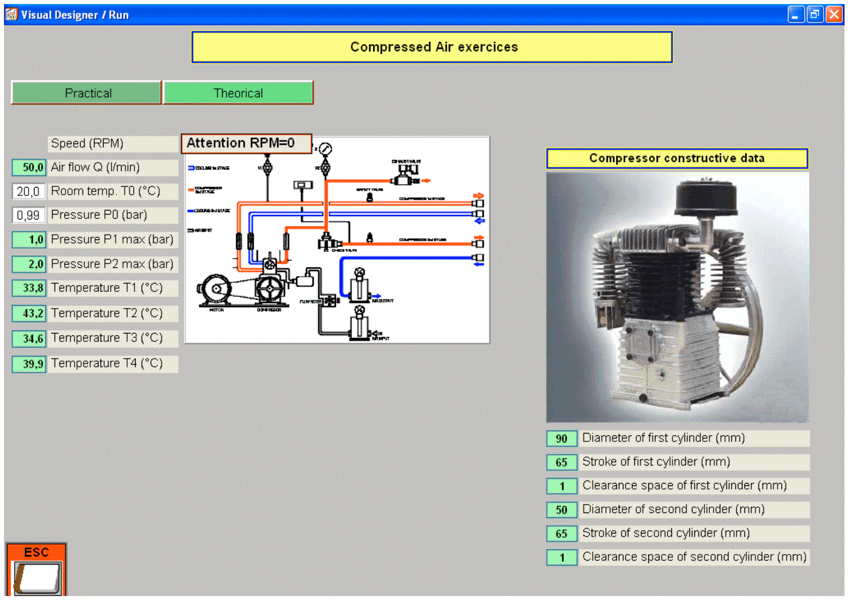


Figure (8) Exercises window.

THEORY:

The air in the compressor will be treated as ideal gas. Thermodynamic properties of air from thermodynamic tables can be used in the calculations. Figure 8 is a schematic of the two stage compressor with intercooler.

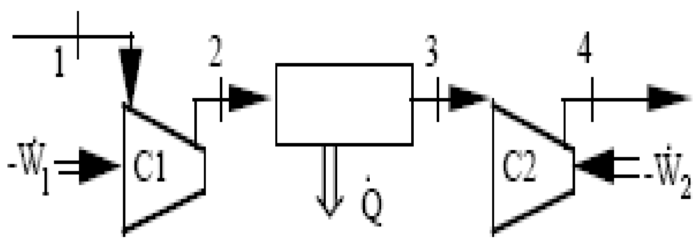


Figure (9) Schematic of the compressors with inter-cooling.

SSSF air compressor, for ideal isentropic compressor, specific work kJ/kg is given as

$$w_{c,s} = h2,s - h1$$

also from second law

$$s2 = s1$$

then at s2 and P2 look up h2,s (if ideal gas is assumed h2,s is found at T2,s) where T2,s found from isentropic relation;

$$T2s = T1(P2/P1)^{k-1/k}$$

for air k =1.4

Also isentropic compressor efficiency is given as,

$$\eta c = w_{c,s} / w_{c,ac}$$

Where $w_{c,ac}$ is the actual work and $w_{c,s}$ is the isentropic work.

For actual compressor use the poly-tropic compression relations

$$T2s = T1(P2/P1)^{(n-1)/n}$$

For the inter-cooling heat lost from compressed air is calculated as

$$Q = mCp(T3-T2)$$

Ideal P-V diagram for a reciprocating compressor is shown in figure 9 and the processes include:

1-2 polytropic compression

2-3 air exhaust at constant pressure

3-4 polytropic of remained air in the clearance volume

4-1 Air intake at constant pressure.

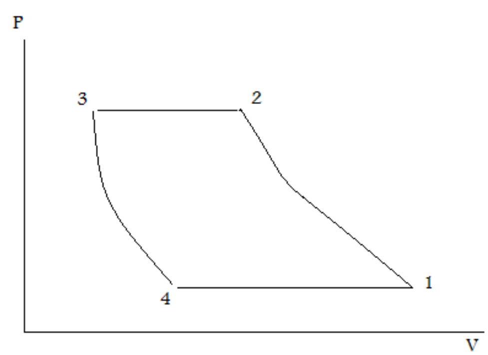


Figure (10) P-V diagram for reciprocating compressor.

Volumetric efficiency, η_v = Air volume drawn in / displaced volume

Displaced volume = (stroke) X (cross –sectional area)

Theoretically volumetric efficiency is given interims of clearance ratio **c**, the pressure ratio P2/P1 as follows;

$$\eta_v = 1 + c - c\left(\frac{P2}{P1}\right)^{1/k}$$

ANALYSIS AND CALCULATIONS :

1. Operate the trainer unit without connection to the storage tank (exhausting compressed air to ambient) exhaust valve is fully open and with/without inter-cooling as connected by your instructor.
2. Set rpm of motor at 1500 (or maximum speed) by adjusting knob 8 in control panel (figure 2) for the compressor unit.
3. On a table record the readings of all parameters that appear on the main diagram by selecting data supervision (see figure 5). In addition record electrical power (current and voltage). See the attached data sheet.
4. Examine the P-V diagram for each stage. Record the intake and exhaust pressure for each stage. Also record the volume % for both stages and for each process including intake, compression, expansion, exhaust (4 values) in addition to the (clearance volume. Compare values with that given in the data supervision.
5. Calculate for each stage compression ratio, intake and exhaust volumes.
6. Calculate air mass flow rate.
7. Assuming ideal gas and constant specific heats calculate polytropic index, specific work for each stage. Compare with values computed by the software-exercises (variable specific heats).
8. Calculate the specific indicated work for each stage from P-V diagrams using software - exercises. Then calculate the power for each stage.
9. Calculate the volumetric efficiency of the first stage, and compare with theoretical value.
10. Repeat experiment at the same rpm but at three different air flow rates. Change air flow by turning the air exhaust valve.
11. Check the effect of the speed on the performance by carrying out analysis for another rpm (half speed).

W_1	W_2	T_1	T_2	T_3	T_4	T_5	T_a	T_{in}	T_{out}	P_1	P_2	Q	H_1	H_2	Total Power
Full speed ( )															
Open exhaust valve (1 turn)															
Open exhaust valve (2 turns)															
Open exhaust valve (3 turns)															
Open exhaust valve (4 turns)															

W_1:-Motor rotational speed (rpm)
W_2:-Compressor speed (rpm)
T_1:-air temperature of the inlet compressor port ^oC
T_2:-air temperature of the first outlet compressor port ^oC
T_3:-air temperature of the second inlet compressor port ^oC
T_4:-air temperature of the second outlet compressor port ^oC
T_5:-Cooler temperature ^oC
T_a:-ambient temperature ^oC

T_{in}:-inlet atmosphere temperature ^oC
T_{out}:-outlet temperature ^oC
P_1:-air pressure of the first outlet port (bar)
P_2:-air pressure of the second outlet port (bar)
Q:-air flow rate (l/min)
H_1:-air humidity of the atmosphere
H_2:-air humidity of the second outlet port
Total power:-Power1+Power2 (KW)

Measuring Parameters from the 1st & 2nd stage P-V Diagram

No. of stages	1st stage				2nd stage			
	Start		End		Start		End	
	P(bar)	V%	P(bar)	V%	P(bar)	V%	P(bar)	V%
Intake Stroke								
Exhaust Stroke								
Clearance Volume%								
Intake Volume								
Intake Pressure								
Exhaust Volume								
Exhaust Pressure								

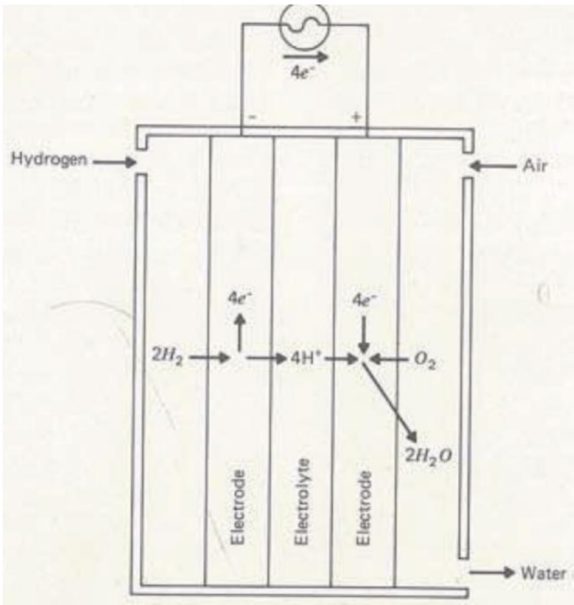
EXPERIMENT No. (7)

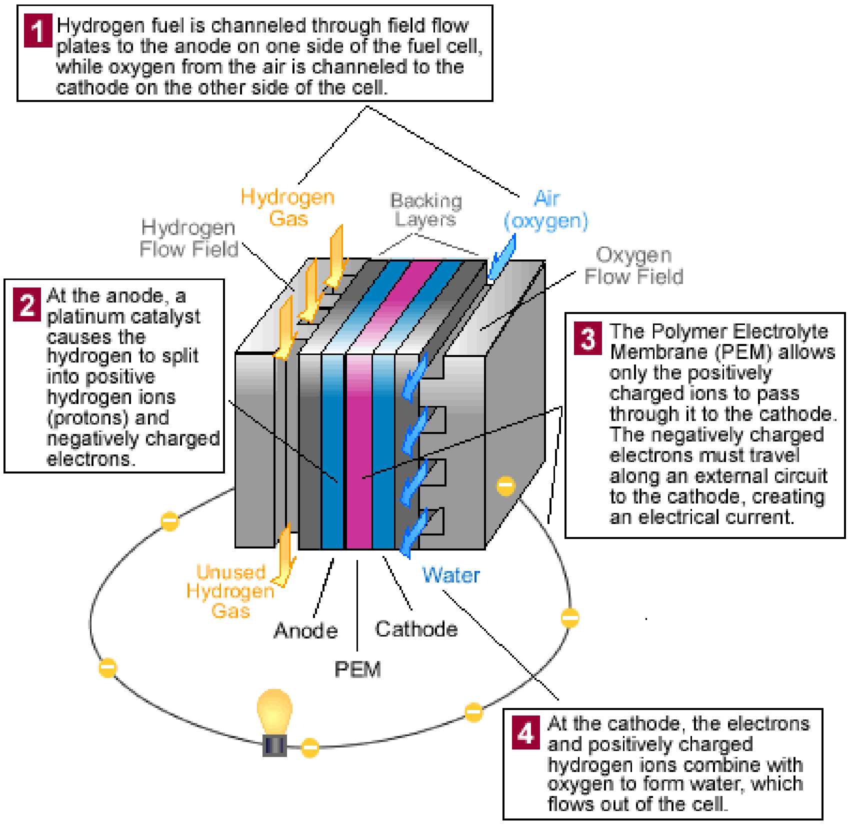
HYDROGEN FUEL CELL

Introduction

Fuel cell is a device in which chemical energy is converted directly to electrical energy. Fuel cell can operate continuously for a long time as long as fuel is supplied to electrodes. The basic principle of operation is the creation of two chemical reactions; one reaction releases electrons that travel through an external circuit and return to be absorbed in the second chemical reaction.
The two reactions occur on two electrodes, which are separated by a liquid or solid electrolyte through which ions will travel.

The hydrogen which is the fuel, reacts on the anode surface producing electrons and ions.
Anode reaction: $2H_2 \longrightarrow 4e^- + 4H^+$
The produced electrons travel through the external circuit to the cathode, while H^+ ions migrate through the electrolyte to the cathode where it combines with electrons and oxygen to form water.
Cathode reaction: $4H^+ + 4e^- + O_2 \longrightarrow 2H_2O$
The electrolyte in this case is an acidic medium.





<u>Theoretical performance</u>:

Consider the fuel cell as a control volume operating at steady state steady flow. Then the maximum work that can be obtained is equal to the reversible work, W_{rev}, which is given as

$$W_{rev} = \Delta H - T\Delta S$$

$$\Delta H = H_p - H_R = \sum_p n_e h_e - \sum_R n_i h_i$$

$$\Delta S = S_p - S_R = \sum_P n_e s_e - \sum_R n_i s_i$$

Where $h = h_f^o - \Delta h 298" \rightarrow "T$
See table A.5 for h , Δh and s
But g = h –T_s Gibbs free energy
For isothermal process $\Delta G = \Delta H - T\Delta S = W_{rev}$
For hydrogen oxygen fuel cell

$$\Delta g = g\ \mathrm{H2O} - gH2 - \frac{1}{2} gO2$$

Table gives typical values for Gibbs energy at selected temperatures.

Temperature ^oC	Water form	Δg	*Reversible EMF, Volt*	*Reversible or max efficiency*
25	Liquid	-237.2	1.23	83
80	Liquid	-228.2	1.18	80
80	Gas	-226.1		
100	Gas	-225.2	1.17	79
200	Gas	-220.4	1.14	77

Theoretical conversion, or maximum efficiency $\varepsilon = \Delta G / \Delta H = 1 - T\Delta S / \Delta H$
ΔH represents heating value of fuel. This represents the maximum cell efficiency.

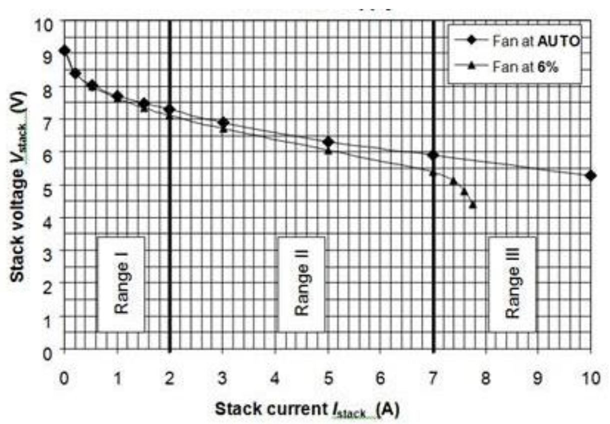
Per mole of hydrogen heating value Δh is known as higher heating value if water product in the liquid state and is equal -285.84 kJ/mole. Lower heating value if water in product is steam and heating value equals -241.83 kJ/mole
Fuel cell actual efficiency = electric power/ heating value of fuel.

<u>Electrical work</u>
Reversible voltage (EMF) = E
$E = -\frac{\Delta g}{2F} = -\frac{\Delta g}{2x96485}$ volts
For example at 200 ^oC Δg = -220kJ hence E=1.14 Volt
The above voltage is the open circuit voltage OCV
Cell efficiency = Cell voltage /1.48 based on HHV and
Cell efficiency = Cell voltage/ 1.25 based on LHV

Defining fuel utilization coefficient μ_f = mass of fuel reacted on cell / mass of fuel input to cell.

Hence cell efficiency becomes $\eta = \mu f \frac{Vcell}{1.48}$
May assume μ_f =0.95

Fuel cell characteristic curves
Typical Voltage versus current curve is shown in figure



Fuel cell irreversibility includes;

- Activation losses Portion of voltage generated is lost in driving the chemical reaction that transfer electrons from the electrodes.
- Internal current: Electron conduction through the electrolyte.
- Ohmic losses: voltage drop as current flow through the electrodes and interconnections.
- Concentration losses: this results from the change of concentration on reactants at the surface of electrodes.

Combining all these irreversibilities in one equation shown below;

$$V = E - ir - A\ln\left(\frac{i + in}{io}\right) + m\,e^{-ni}$$

Where E is reversible OCV

i_n is the internal current density from fuel crossover.

A is constant representing the slope of the Tafel line

i_o exchange current densities either at cathode or anode.

m & n are constants

r is the area specific resistance.

Oxygen and air flow rates:

$$Oxygen\ flow = 8.29x10^{-8}x\frac{Pe}{Vc}kg/s$$

$$Air\ flow = 3.57x10^{-7}x\frac{Pe}{Vc}\ kg/s$$

Hydrogen flow rate

$$Hydrogen\ flow = 1.05x10^{-8}\frac{Pe}{Vc}\ kg/s$$

Water production

$$Water\ production = 9.34x10^{-8} x \frac{Pe}{Vc}\ kg/s$$

In above equation P_e is the total stack power, V_c is the cell average voltage.

Fuel cell useful performance equations

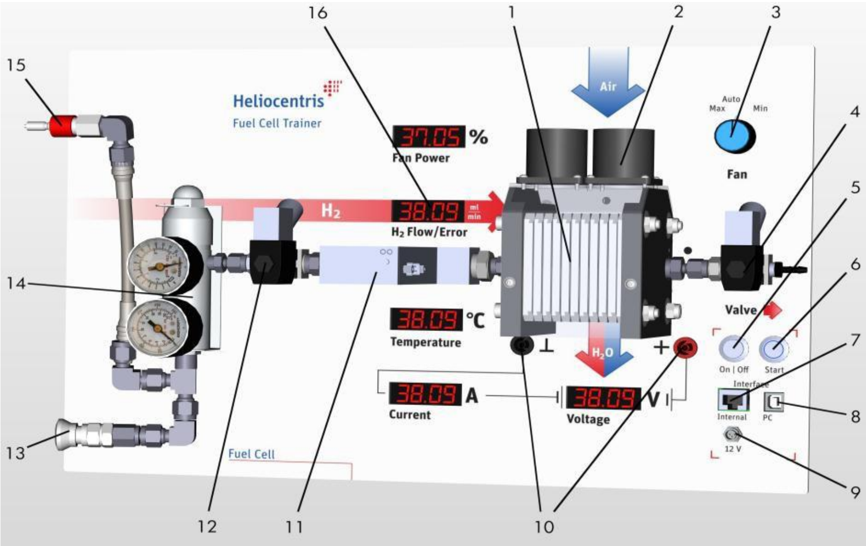
1.	Faradays First Law:	$m = ECE \cdot I \cdot t$
2.	From the Second Law, the electrochemical equivalent ECE can be written as:	$ECE = \frac{M}{z \cdot F}$
3.	Equating the two expressions of ECE we have:	$\frac{m}{I \cdot t} = \frac{M}{z \cdot F}$
4.	Rearranging for the number of moles n:	$n = \frac{m}{M} = \frac{I \cdot t}{z \cdot F}$
5.	The rate of substance change is:	$\dot{n} = \frac{I}{z \cdot F}$
6.	For each oxygen molecule four electrons are transferred in the conversion, as seen in the half cell cathode reaction:	$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

<u>Objective</u>

- Know parts and structure of fuel cell
- Measure characteristic curve of fuel cell
- Analyze effect of fuel flow on performance.
- Analyze effect of air flow on performance
- Analyze effect of temperature on performance
- Calculate efficiency of fuel cell
- Experience some applications of fuel cell.

APPARATUS DESCRIPTION:

Fuel Cell Module



1 Fuel cell stack	2 Fan
3 Rotary switch for fan	4 Purge valve
5 ***On / Off*** switch	6 ***Start*** button with operating status LED (operation, standby and error)
7 RJ45 jack internal communication ***Internal Interface***	8 USB connection for the PC ***Interface***
9 Power supply input ***12 V***	10 Power output
11 Flow meter for hydrogen	12 Solenoid valve
13 Quick coupling for Connection Kit for compressed hydrogen cylinder or hydrogen generator	14 1-stage pressure reducer with inlet pressure gauge (bottom)
15 Quick coupling for metal hydride canister	16 H_2 flow display and error code ***H_2 Flow / Error***

Fuel Cell Stack

The fuel cell module is the central element of the Fuel Cell Trainer. The fuel cell stack (1, referred to hereinafter as stack) is designed for hydro- gen-air operation. Hydrogen is supplied from the quick coupling bridge through the pressure reducer (12). The air is drawn in from the environment by the fan (2) and supplied to the stack. The air provides for the electrochemical reaction and for the cooling of the stack.

There are 10 fuel cells in the stack connected in a series both electrically and on the hydrogen side. The generated electrical current is discharged to the current collectors located at the ends.

Fan

The power of the fan is adjusted in various ways:

- By the user, with the rotary switch (3, ***Min*** …***Max*** position)
- By the internal control (rotary switch in ***Auto*** position)
- Through the software (see page 53)

The internal control of the fan is dependent on the stack power. It is selected in such a way that sufficient cooling is always assured.

Purge Valve

The purge valve automatically purges the hydrogen channels of the stack in specific intervals during operation. In the process, the accumulated inert gases (primarily water vapor) are blown out.

Microprocessor

The integrated microprocessor monitors the safety-related and operating parameters as well as the communication between the modules and the connected PC, if applicable.

The following parameters can be read on the fuel cell module:

- Hydrogen volumetric flow to the fuel cell module [ml / min] ***H* 2 *Flow / Error***
- Output current of the fuel cell module [A] ***Current***
- Output voltage of the fuel cell module [V] ***Voltage***
- Fan power [%]***Fan Power***
- Stack temperature [° C] ***Temperature***

Pressure Reducer

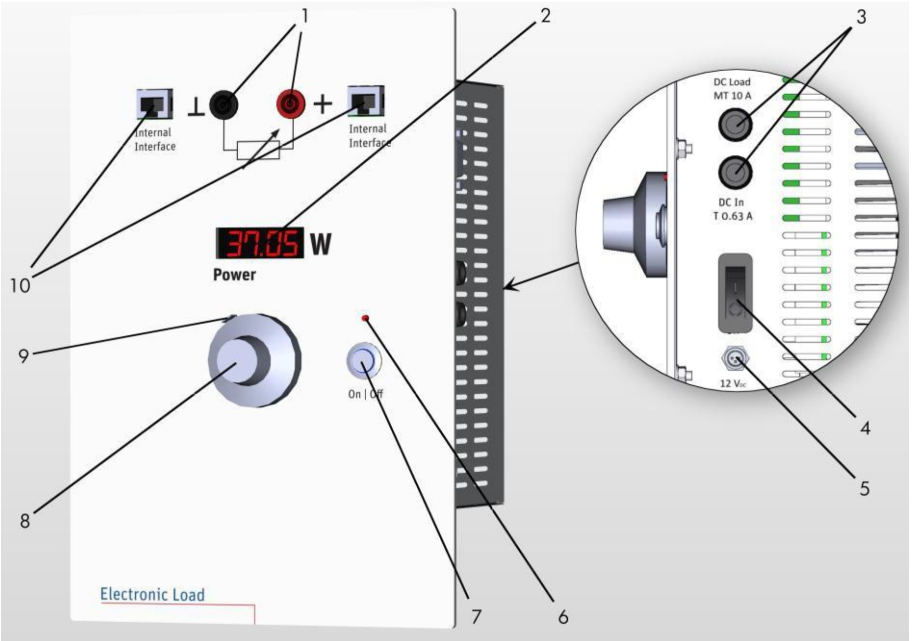
The pressure reducer reduces the pressure of the extracted hydrogen to the constant pressure of approx. 0.6 bar overpressure required for the fuel cell module. It is equipped with an inlet and outlet pressure gauge and has an overpressure discharge on the housing. Therefore, in the event of a defect of the pressure reducer, the outlet pressure is limited to approx. 1 bar and the connected components are not damaged by excessive pressure as a result.

Solenoid Valve Flowmeter

The solenoid valve is closed when deenergized and opens when the fuel cell module is in operation.

The flow meter detects the hydrogen currently consumed by the fuel cell module in operation.

Electronic Load Module



1 Load input
3 Fuses

5 12 V_{DC} supply connection
7 Signalization ***On / Off*** switch for active load (blue)
9 Potentiometer locking device

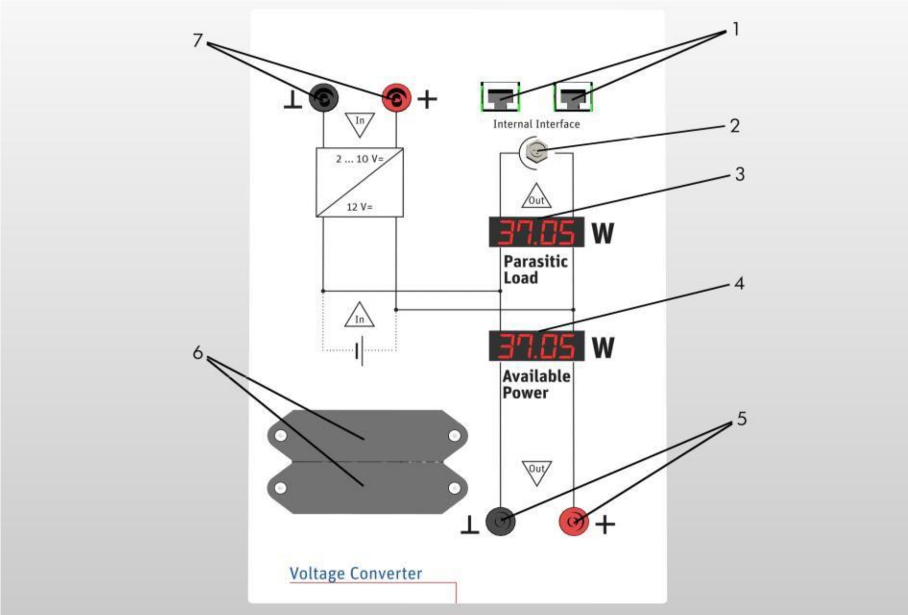
2 Status display of the input line
4 Main switch with LED for operational readiness (orange)
6 Error signalization LED (red)
8 10-turn potentiometer (poti) for the specification of the load current
10 Connection for internal communication ***Internal Interface***

The electronic load is used as a regulated consumer. Its output parameters are optimally adjusted to the fuel cell stack. The electronic load is supplied with voltage from the fuel cell stack and functions like an electronically regulated resistor. It converts the electrical energy into heat in a controlled manner.

The electronic load works in constant current mode. That means any fluctuations of the fuel cell voltage are compensated for and specified current set point is adhered to. This current set point is infinitely adjustable with the 10-turn potentiometer on the front side.

DC/DC Converter Module

The DC/DC converter converts the load-dependent voltage of the stack to a constant direct voltage of 12 V_{DC}. In the process, the self-consumption of the Fuel Cell Trainer is covered and an arbitrary 12 V consumer can be supplied.



1 Connection for internal communication *Internal In terface*
2 Voltage supply output for the supply of the fuel cell module *Out*
3 Status display for the self consumption *Parasitic Load*
4 Status display of the output power *Available Power*
5 12 V_{DC} power output *Out*
6 Battery compartment
7 Power input of the DC/DC converter *In*

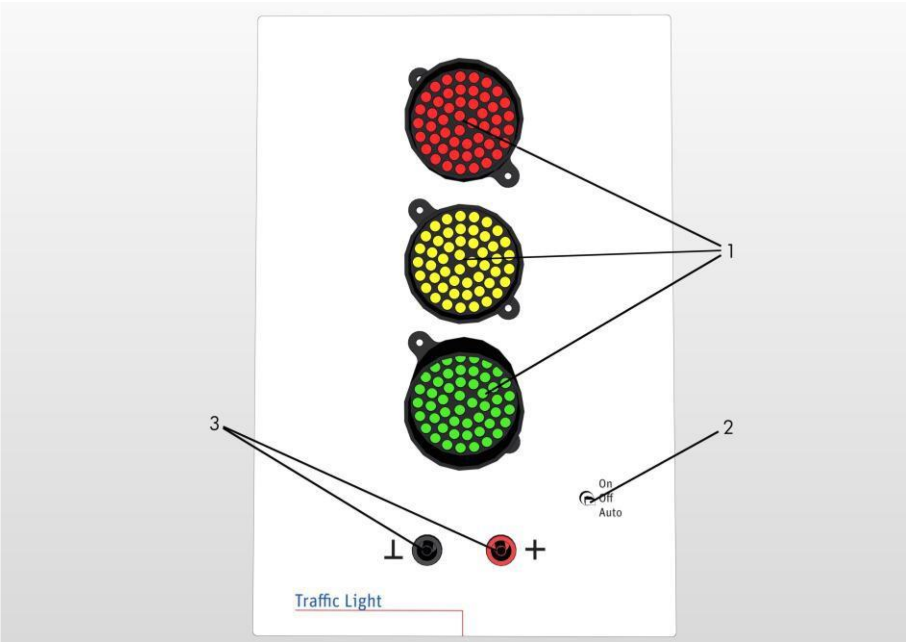
The DC/DC converter is a step-up converter and converts an input volt- age of 2...10 V_{DC} into a regulated 12 V_{DC} output voltage. The fan and microprocessor of the fuel cell module can be supplied with this voltage. The starting voltage of the fuel cell module can be supplied by the batteries integrated in the module during the 10-second system test. The DC/DC converter module thereby enables a grid-independent operation of the fuel cell system.

The DC/DC converter module can also supply other 12 V_{DC} consumers with voltage.

The DC/DC converter is equipped with electronic current limiting. If the output power of the DC/DC converter is exceeded, the input current is limited at the DC/DC converter and the converter is protected from overheating.

Traffic Light Module

The traffic light module is an exemplary 12 V_{DC} consumer for the Fuel Cell Trainer. It is a realistic model of grid-independent supply. Each traffic light segment has a different consumption level and enables a periodic loading of the fuel cell stack.



1 LED traffic light segments

2 Operating mode switch ***On*** , ***Off*** , ***Auto***

3 12 V_{DC} supply input

The operating mode switch has three positions. In the ***Off*** position the traffic light module is switched off. In the ***Auto*** position the lights switch like in a traffic light for roads. In the ***On*** position all 3 traffic light segments are continuously illuminated.

Hydrogen Supply

The system may only be operated with a hydrogen supply provided by Heliocentris.

The fuel cell module requires hydrogen with a minimum purity:

- of 5.0 (=99.999 %) for operation with metal hydride canisters with an inlet pressure of 1…10 bar or
- of 3.0 (=99.9 %) for operation with a different hydrogen supply with an inlet pressure of 1…17 bar.

The pressure reducer reduces the hydrogen pressure to approx. 0.6 bar.

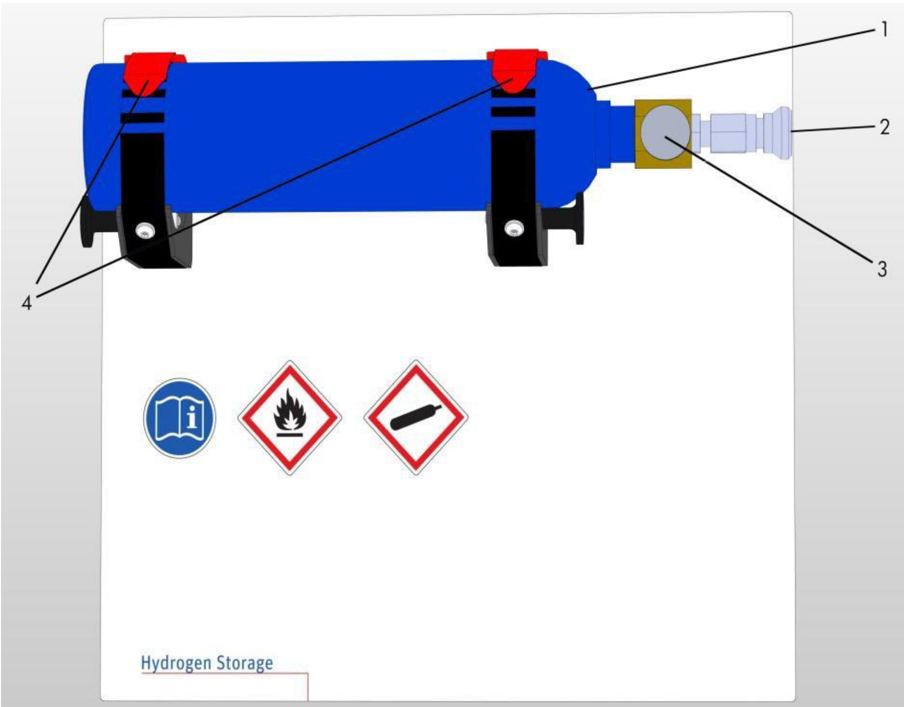
The hydrogen supply can be established as follows:

- Connection kit for compressed gas cylinders
- Metal hydride canister with charging set
- Hydrogen generator with metal hydride canister

The connection of a compressed gas cylinder is only permitted with the 200 bar H_2 Connection kit provided by Heliocentris.

With the use of a hydrogen generator for the filling of the metal hydride canister, the dispensed hydrogen must be dry; otherwise corrosion processes can occur in the hydrogen system. A purity of 5.0 indicates sufficient trying of the electrolytically generated hydrogen.

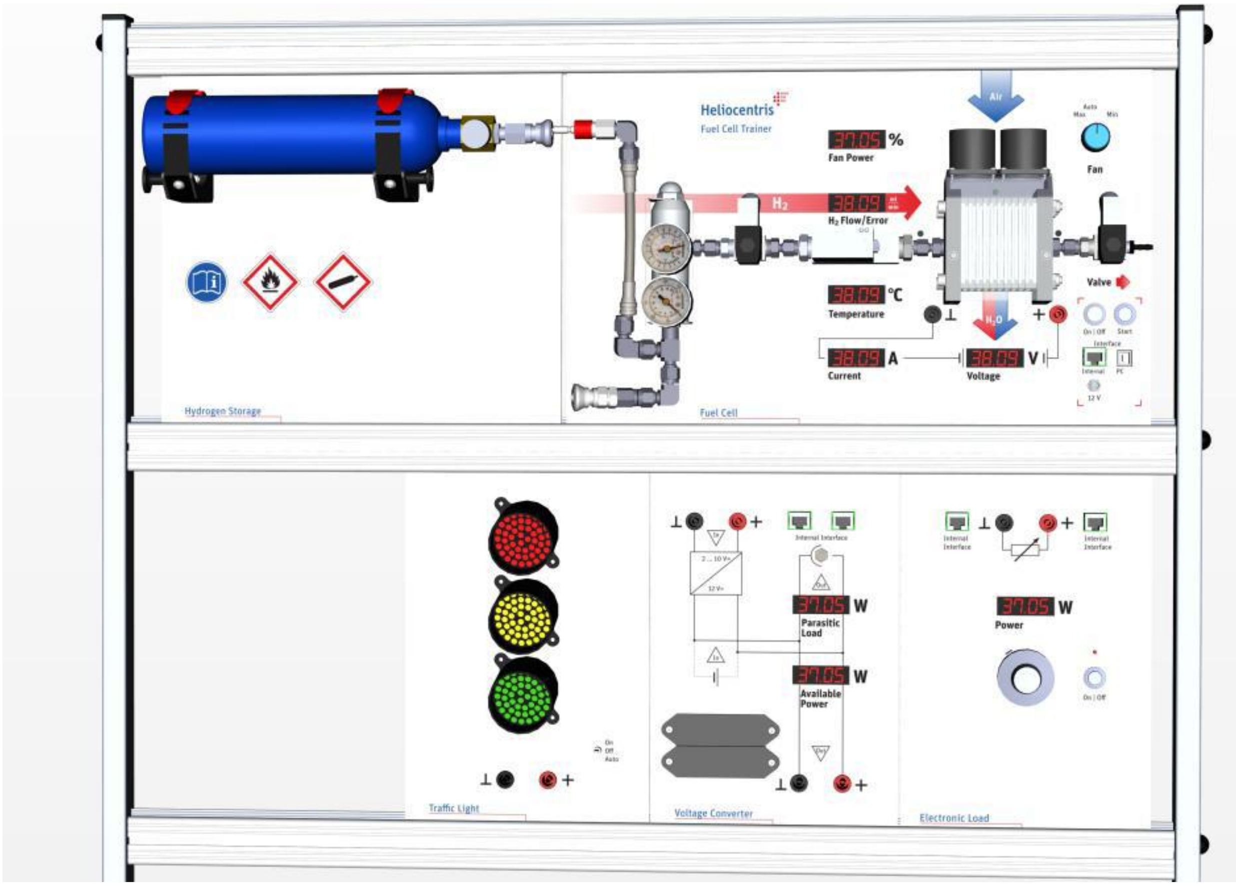
Hydrogen Storage Module



1 Metal Hydride Canister 2 Quick coupling
3 Stop valve for metal hydride canister 4 Mount with hook and loop fastener

The hydrogen storage module supplies the Fuel Cell Trainer with hydrogen. The metal hydride canister is supplied in a separate package and filled with protective gas.

Fuel cell system experimental unit parts



Part I

Voltage and power –current curves (variable hydrogen flow & constant cell temperature)

In this experiment we determine the voltage-current characteristic of a fuel cell and plot a power-current diagram. This provides a basic knowledge of the behavior of a fuel cell. The results can be used to size and design fuel cell stacks.

Objectives of this part

- Recording measured values
- Drawing and evaluating the voltage-current-curve and the power-current-curve
- Comparing with the theoretical behavior of fuel cells
- Interrelation between the different physical values of a fuel cell

Experimental Procedure

For these measurements, the fuel cell should be at a temperature of 40 °C.

1. You can reach this temperature by loading the fuel cell for a few minutes with a current of approximately 5 A.
2. Using the potentiometer of the EL100, increase the load current until the ***Current*** display on the FC50 shows approximately 5 amperes.
3. To further cause stack temperature to rise, turn the rotary switch for fan power on the FC50 so the ***Fan Power*** display indicates 10%.

After the temperature reaches 40 °C, ensure the load potentiometer is turned back to 0 and set rotary switch for fan power to ***Auto***.

When measuring the first point (no-load operation) turn the ***On/Off*** switch on the EL100 into its original position ***Off*** to ensure that there is no load on the fuel cell (switch is no longer illuminated).

4. Using the EL100 potentiometer, set in turn each load current listed in the part one data sheet table.
5. After waiting at least 60 seconds at each point, record the measured values of stack current I_{stack} ***Current*** display, stack voltage V_{stack} ***Voltage*** display and hydrogen flow rate V***H***2 ***Flow/Error*** display in the table.

If you are not making further measurements with the system, proceed to shut down and switch off the system

Analysis & calculations

1. Draw the fuel cell voltage-current relation $V_{stack} = f\,(I_{stack})$ and describe the characteristic curve.
2. Calculate the stack power $P_{Stack} = I\ stack * V_{stack}$ and record the results in the table
3. Draw the fuel cell power-current relation.

4. From the results of your measurement of the stack at a load current of 10 A, determine the voltage and the current density of an individual cell, (in A/cm2).

5. Plot the measured hydrogen consumption as a function of current in a diagram: V_{H2} = f (I_{stack})
6. Describe and explain the characteristic curve. Then explain the observed behavior in no-load operation (I_{stack} = 0 A).

$$\frac{\dot{V}_{H2}}{I} = \frac{a \cdot V_m}{z \cdot F}$$

7. Determine the stack efficiency η_{stack} of this fuel cell, then plot versus stack current, comment on the curve.

$$\eta_{stack} = \frac{P_{out}}{P_{in}} = \frac{V_{stack} \cdot I_{stack}}{LHV \cdot \dot{V}_{H2}}$$

Note: The displayed values of hydrogen flow rate have been converted to the equivalent ml/min at standard conditions (0 °C, 1.01325 bar). The heat value of hydrogen at standard conditions is LHV = 10.8 MJ/m^3 .

8. Determine the voltage efficiency η_V of the fuel cell from the measured values. Perform the calculation with the reversible thermodynamic voltage related to the lower heat value (LHV) of hydrogen. Also determine the current efficiency η_I and then calculate the stack efficiency η_{stack} from both. Note : The values of the hydrogen flow rate are converted to standard conditions (0 °C, 1.01325 bar). The reversible thermodynamic voltage related to the lower heat value LHV of hydrogen is V_{rev} LHV = 1.254 V, the Faraday constant F = 9.648×10^4 C/mol and the molecular standard volume V_m = 22.4 L/mol.

$$\eta_V = \frac{V_{stack}}{a \cdot V_{rev\,LHV}}$$

$$\eta_I = \frac{I_{stack}}{I_{th}} \quad . \quad I_{th} = \frac{\dot{V} \cdot F \cdot z}{a \cdot V_m} \quad .$$

$$\eta_{stack} = \eta_V \cdot \eta_I$$

Part II

Effect of the air supply on the characteristic curve of a fuel cell

In these experiments we investigate the effects of reduced air supply on the characteristic curve of the fuel cell.

Objectives

- Investigating the effects of reduced air supply on the V-I curve
- Applying Faradays laws

Experimental Procedure

- For the first series of measurements place the fan setting at ***Auto***
- Repeat procedure of part I above steps 1 to 5
- For the second series, adjust the control so that Fan Power is 6%. And repeat steps 1 to 5 again.

Analysis & calculations

1. Use the measured values to draw on a diagram the voltage-current characteristic V_{stack} = f(I_{stack}) of the fuel cell for both fan settings. Briefly describe the shape of the resulting characteristic curve.

2. Calculate the associated stack power P_{stack}. From the measured data and plot versus current from both air flows. Comment on curves.

3. Calculate the oxygen flow rate needed at an individual cell and the rate of water formation in order to produce an electric current of 10 A. Use a formula derived from Faradays laws for the determination of the substance change. Then determine the theoretically needed volumetric air flow for the entire stack on the assumption that the usable oxygen portion in air is 20 %. Consider the number of cells of the stack.

<u>Part III</u>

Effect of the temperature on the characteristic curve of a fuel cell experiment

Effect of fuel cell temperature on its performance such voltage- current, power- current curves will be investigated. For this purpose fuel cell will be operated on two different temperatures first series at 28 ^{o}C and the second data set at 44^{o}C. During the experiment temperatures will unavoidably drift.

Experimental Procedure

In order to keep the deviations small, currents and voltages should be measured and recorded as quickly as possible.

- The recommended temperatures at the beginning of each series are approximately 28 °C and 44 °C.
- It is recommended to take first the series of measurements at the lower temperature. If the temperature is already too high, you can use the fan to lower it.
- Cool the fuel cell as quickly as possible to avoid drying the mem-branes.
- After reaching the desired operating temperature, reset the fan control to ***Auto***.
- To reach the fuel cell temperature of the second series of measurements load the fuel cell for a few minutes with a current of approximately 7 A.
- Using the potentiometer of the EL200, increase the load current until the Current display on the FC50 shows approximately 7 amperes.
- To further cause stack temperature to rise, turn the fan control knob on the FC50 so the Fan Power display indicates 12%
- After the temperature reaches 44 °C, ensure the load potentiometer is turned back to zero and set fan control knob to ***Auto.***

- Use the load potentiometer of the EL200 to set in sequence the current values given in the data sheet table.
- Wait for at least 15 s at each current setting before copying the measured values of stack current I_{stack} and stack voltage V_{stack} to the measured value table.

- Begin the first series of measurements at a stack temperature of approx. 28 °C, the second series of measurements at approx. 44 °C.

Analysis & calculations

1. Draw the voltage-current characteristic curve for each operating temperature and describe the shape of the curve.
2. Explain the described characteristic curves considering the electro-chemical reaction occurring here and the electrical conductivity.
3. Draw conclusions about the optimum operating temperature.
4. By which measure can the optimal operating temperature be increased? Draw on your conclusions in question 2 and consider whether the effect is applicable in every case

Hydrogen Fuel Cell

<u>Data Sheet</u>

Nominal	Measured values at T= 28 ^{o}C		Measured values at T= 40 ^{o}C / Fan auto			Fan 6%	
I_{stack} (A)	I_{stack} (A)	V_{stack} (V)	I_{stack} (A)	V_{stack} (V)	Hydrogen flow ml/min STP	I_{stack} (A)	V_{stack} (V)
0.2							
0.5							
1							
1.5							
2							
3							
5							
7							
10							

EXPERIMENT No. (8)

SOLAR ENERGY MINILAB

Figure (1) Solar Energy Minilab

1. General Characteristics of Silicon Solar Cells

Barameters characterizing a silicon solar cell are:

a) Short-circuit current I_o :

It is the value of the current intensity, delivered by photovoltaic cell in correspondence with given value of incident-radiation intensity (W/m^2), with a given temperature, for a given value of the lighted surface of the cell and for null value of load resistance.

b) No-Load voltage V_O :

It is the potential difference, measured at the ends of the open-circuit cell, in relation to a given radiation-intensity and to a given temperature of the cell.

c) Optimum working-current I_{opt}
Optimum working-voltage V_{opt}
Optimum working-resistance $R_{opt} = V_{opt} / I_{opt}$:

They are the values of the delivered current, of the delivered voltage, and of the load resistance, corresponding to the maximum electric power supplied by the cell, i.e. to the optimum working-point.

d) Efficiency η :

The efficiency η of a solar cell is the ratio between the highest electrical power delivered by the cell ; and the power of the radiation incident to its surface ; at present η is not over 15%.

e) Top working-temperature T_L :

It is the highest temperature, which the cell can work at ; it reaches about 120 ^oC.
Fig. (1) carries the typical voltage-current curves, of a common silicon cell, in relation to different values of incident power density (mW/cm^2), and the constant values of the temperature and of the radiation surface of the cell. Notice how, as the power density, incident to the cell, increases, also the highest delivered electrical power increases (as you can see from the isopower curves) and the optimum working-resistance decreases.

2. Study of the current, delivered by photovoltaic cell, in relation to the variation of its orientation towards the light source

The solar cell receives the maximum radiation-flux, and so it delivers the maximum short circuit-current intensity, when it is oriented perpendicularly to the direction of light rays.
On the contrary, if these rays form an angle θ with the normal to cell-surface, the luminous flux, reaching the cell, is reduced by a factor equal to $\cos\theta$ and consequently the delivered current is :

$$I_\theta = I_o \cos\theta$$

where Io is the intensity of short circuit current delivered when $\theta = 0$.
You can verify this law, by measuring the short circuit currents, delivered by the cell, in relation to different angles θ.
You can carry out the test in laboratory, using the tungsten lamp of
100 W, at your disposal in Solar Energy Minilab, as artificial light-source. This lamp gives off a light beam, being directional enough to allow solar-radiation simulation, at distances included from 10 to 50 cm.
The experimental arrangement of the elements may be that indicated in Fig (1).

Start the test by placing the lamp perpendicularly to the sensitive surface of the photovoltaic cell ; you can control the exact perpendicular position of light rays, by controlling that the cell-edges project no shadow on the supporting plane of the cell itself.
After verifying that the photovoltaic cell does not deliver any current, when the lamp is out, that means that there aren't any light sources able to influence the measurements, you can switch on the tungsten lamp.
Under these experimental conditions the voltametric device, duly short circuited, measures a potential difference being almost null and a short circuit-current intensity I_o (A).
Now, if you change the inclination of the supporting plane of the stand in relation to the horizontal plane by an angle θ, measurable by a goniometer (which is the same as keeping fixed the supporting plane of the stand, where the solar cell is set, and changing the incident radiation by an angle θ in relation to the normal to cell-surface), you do nothing but reduce the "useful" surface of the cell, and consequently the quantity of intercepted radiation.
At every new positioning it is very important to verify the exact angular position of the cell under the lamp by a ruler, as well as the exact distance between these two elements.
In a table show the different measured I_θ (mA), the ratios I_θ/I_o,
and the theoretical values of cosθ curve, according to different values of the angle θ

Plot the ratios I_θ/I_o versus θ and compare with the theoretical cosθ curve.

3. <u>Measurement of electric characteristics of a silicon cell :</u>

<u>Voltage-Current curves</u>

Explaining the general characteristics of a solar cell (paragraph 1), we have seen that the solar cell represents a non-linear electric device ; then it is necessary to draw its characteristic voltage-current curve, by varying the inserted load in relation to a given value of lighting.
You can achieve this type of test in laboratory, carrying out the arrangement of Fig. (2).
After verifying that, when the lamp is out, the photovoltaic cell does not generate any current under null-load conditions (short circuited cell), (that means that there is no light-source influencing the measurements), you switch on the tungsten lamp and position the potentiometers of coarse adjustment and of trim to their highest values.
In this arrangement, corresponding to an open circuit, the ammeter indicates a null current, where as the voltmeter indicates the no-load voltage V_o.
Now, reduce the resistance of the potentiometer of coarse adjustment slowly, keeping the one of trim at zero.
At first, the voltage decreases rather slowly, until, at a certain moment, the measured current increases suddenly and then it keeps nearly constant.
So, for carrying out voltage-current measurings, it is suitable to operate by small steps with the potentiometer of coarse adjustment, and to carry out measurements exactly and by regular steps, acting on the potentiometer of trim.
When the potentiometer are at their lowest value, the resistance is null practically, consequently the voltage would go to zero. You can verify this behavior, excluding the potentiometer and short circuiting the output of the volumetric instrument by one of the connectors used for connection of this instrument with the potentiometer.

Under these conditions you can make the measurement of short circuit current.
It is important to become familiar with the use of the two potentiometers so as to be able to carry out the detection of the data along the voltage-current curve carefully.
The two potentiometers are connected in series and have a resistance of about 10 ohms (trim) and of about 500 ohms (coarse adjustment).
In this way, putting the potentiometer of coarse adjustment to zero, and apportioning on the trim-one, it is possible to vary the resistance by values of few ohms : this allows us to detect the voltage-current characteristics below 400 mV carefully.
Successively, operating on the potentiometer of coarse adjustment, you can detect the area of the curve, where the current becomes null and the voltage becomes maximum.
Then it is clear that the series-connection of the two potentiometers allows to carry out really accurated measurings of the characteristic curves, with a certain experience.
In a table give the data, V, I, P, plot I, P versus V and discuss the results.

4. ***Determination of solar-cell characteristics in relation to different light intensities***

If you want to draw an aggregate of characteristic voltage-current curves, delivered by a silicon cell, it is necessary to operate by the same experimental device and following the instructions, described in the precedent paragraph, but having the care of changing the light intensity of the cell.
If you carry out the measurements in laboratory and use a tungsten lamp, it is sufficient to vary the lamp-cell distance in order to vary the lighting-degree of the cell. Remember that in this case the light intensity, striking the cell, varies with the inverse of the square of the lamp - photovoltaic-cell distance.
Using the distances 13, 16, 21 cm establish the I - V characteristic curve for the solar cell at each distance.

Plot I_O, V_O versus incident power density. Discuss the results.

Data Sheet

Part 1 : Short Circuit

Height (cm)	Degrees	Voltage (V)	Current (mA)
H1 =	0		
	30		
	45		
	60		
H2 =	0		
	30		
	45		
	60		
H3 =	0		
	30		
	45		
	60		

Part 2 : with Load
100% intensity at 0 degrees

Height (cm)	Voltage (V)	Current (mA)
H1 =		
H2 =		
H3 =		

H3 at 75% Intensity

Voltage (V)	Current (mA)

H3 at 50% Intensity

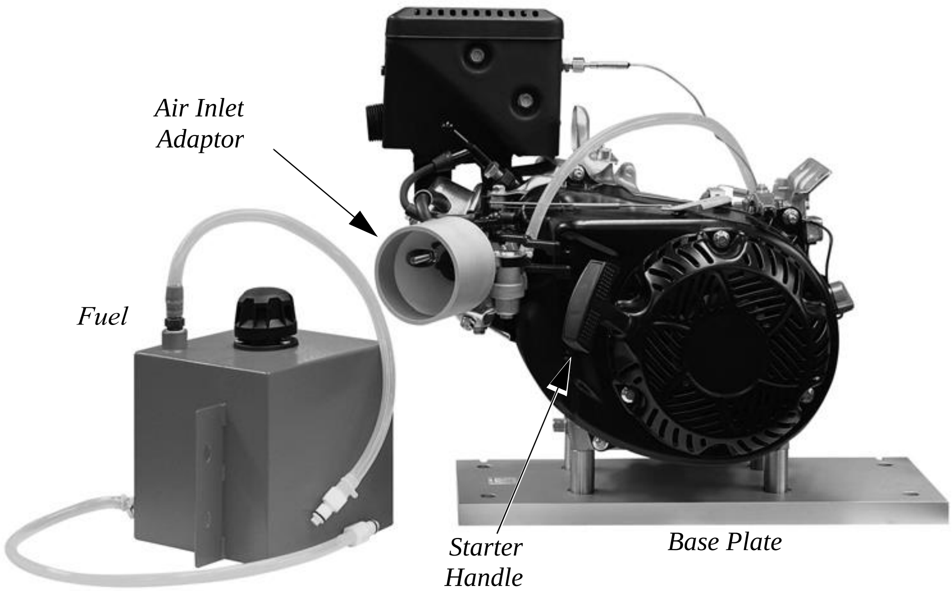
Voltage (V)	Current (mA)

H3 at 100% Intensity for small Cell

Voltage (V)	Current (mA)

EXPERIMENT No. (9)

FOUR STROKE PETROL ENGINE



Layout of the TD201 Engine

The TD201 made from a small air-cooled single cylinder petrol engine with:

- overhead valves - one for inlet, one for exhaust
- a conventional carburettor with manual choke
- electric spark ignition
- splash lubrication
- recoil starter

The engine includes a governor that stops the engine running too fast. The governor is a centrifugal device inside the engine. Rods, levers and springs link the governor to the carburettor. When the engine speed increases to a certain level, the governor forces the carburettor to reduce the fuel/air mixture that enters the cylinder. This regulates the maximum speed and engine power.

The engine is lubricated by ordinary engine oil, stored in a small sump at the base of the engine body. The engine crankshaft splashes the oil around inside the crankcase, to lubricate the lower cylinder wall and the crankshaft bearings.

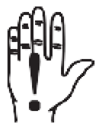
The engine is a cross-flow design, so that the fuel/air mixture enters from one side of the cylinder head and is forced out as exhaust to the opposite side of the cylinder head.
Forced air-cooling is provided by the fins around the engine flywheel. As the flywheel turns, the fins force air around the cylinder by means of simple ducting.
The engine is started by a starter handle and cord, wrapped around a pulley on the flywheel. The pulley includes a clutch to disengage the cord and pulley when the engine starts. This arrangement is called a ‘recoil starter’

The flywheel has a permanent magnet fixed to its edge, as the flywheel turns, the magnet passes the primary winding of the electric ignition coil and forces an electric current to flow in the coil. The ignition system uses this to create a spark at the spark plug. The engine includes an on off switch that connects the primary winding to ground to stop the ignition circuit, this stops the engine.

Technical Details.

Absolute Maximum Power	5.2 kW (7 hp) at 3600 rev.min^{-1} Gross output to SAEJ1995 tests and without air cleaner and exhaust
Net Power	4.5 kW at 3600 rev.min^{-1} 2.2 kW at 1800 rev.min^{-1}
Bore	70 mm
Stroke/Crank Radius	54 mm/27 mm
Connecting Rod Length	84 mm
Engine Capacity	208 cm^3 (0.208 L) or 208 cc
Compression Ratio	8.5:1

WARNING



- Do not touch the Test Engine or the exhaust pipework while the equipment is running. Let them cool down before you touch them.
- Never work alone with this machinery. A qualified lecturer or supervisor must be present whenever it is used.
- All users must wear ear and eye protection.

Engine Start

1. Make sure that the Test Engine Fuel Tank has enough fuel for your test.
2. Switch on the electrical and water supplies to the TD200 Test Bed.
3. Open any fuel taps on your Fuel Gauge to allow fuel to flow to the Test Engine. If necessary, tap the fuel line to remove any air bubbles.
4. If the Test Engine is cold, fully shut the choke device on the carburetor. If it is still warm, set the choke to half open.
5. Adjust the engine throttle (speed control) to half-way.

6. Switch the ignition switch to ON position then start the engine using the special key, release the key immediately when the engine start. If the engine didn't start didn’t keep cranking too much to avoid the starter failure.

7. Allow the engine to run for a few minutes until it reaches normal operating temperature and runs steadily.

8. Fully open the choke.

- Full Throttle Test (Engine Performance).

Engine, Fuel and Ambient Conditions:

Engine type	Single Cylinder
Engine size (Litres)	0.208
Engine Cycles (stroke)	4
Fuel type	Petrol/gasoline
Fuel Density (kg.m^{-3})	740
Fuel Calorific Value (MJ.kg^{-1})	43.8
Ambient Air Pressure (mbar)	1010
Airbox orifice dimensions (m)	0.0185
Throttle/Rack Position	Full

Fuel	Lower Calorific Value (MJ.kg^{-1})	Stoichiometric air/fuel ratio	Density (kg.L^{-1})	Density (kg.m^{-3})
Petrol/Gasolene	43.8	14.6	0.74	740
Diesel	39		0.84	840
Light Fuel Oil	40.6		0.925	925
Medium Fuel Oil	39.9	14.4	0.95	950
Heavy Fuel Oil	39.7		0.965	965

Theory and Equations.

Item	Symbol	Units	Actual Value
Coefficient of Discharge for the Orifice	C_d		0.6
Calorific Value of Fuel	C_L	$J.kg^{-1}$	
Specific Heat of Air at Constant Pressure	C_P	$J.kg^{-1}K^{-1}$	
Orifice Diameter	d	m	
Ambient Pressure	p_A	Pa	
Engine Speed	N	$Rev.min^{-1}$	
Ambient Air Temperature (at inlet)	T_A	°K	
Pressure change	(Δp)	Pa	
Enthalpy of Air	H_A	W	
Combustion Energy of Fuel	H_F	W	
Heat Lost to Exhaust	H_{LE}	W	
Gas Constant for Air	R	$J.kg^{-1} K^{-1}$	$287 J.kg^{-1} K^{-1}$
Air Velocity	U	$m.s^{-1}$	
Air Density	ρ	$kg.m^{-3}$	
Mass Flow of Air	$\dot{m}a$	$kg.s^{-1}$	
Mass Flow of Fuel	$\dot{m}f$	$kg.s^{-1}$	
Volumetric Efficiency	η_V	%	
Thermal Efficiency	η_T	%	
Brake Mean Effective Pressure	BMEP	bar	

Mass and Volume Flow

Many of the calculations need the mass flow of a liquid, but the instruments read volume flow. This is because the mass flow depends on the density of the liquid, which can vary with temperature. The relationship between mass and volume of a liquid is:

$$\text{Mass} = \text{Density} \times \text{Volume}$$

So:

$$\text{Mass Flow (in kg.s}^{-1}\text{)} = \text{Density (in kg.m}^{-3}\text{)} \text{ x (Volume Flow (in L.s}^{-1}\text{)/1000)}$$

Air Consumption

The Air box includes an orifice at its inlet. The DPT1 Instrument Module shows the ambient air pressure (before the orifice) and the air pressure in the Air box (after the orifice). The difference in the pressures (Δp) and the air density (ρ) will give you the basic air flow velocity (U):

$$U = \sqrt{\frac{2\Delta p}{\rho}}$$

To find the mass flow the $\dot{m}a$ flow velocity equation is modified to separate out the factors of density and to include the coefficient of discharge (C_d) for the orifice and the orifice diameter:

$$\dot{m}_a = C_d \frac{\pi d^2}{4} \sqrt{\frac{2 p_A \Delta p}{R T_A}}$$

Fuel Consumption

To find the mass fuel consumption you need the volumetric fuel flow and the fuel density:

Mass Fuel Flow (in $kg.s^{-1}$) = Fuel Density ($kg.m^{-3}$) x (Fuel Volume Flow ($L.s^{-1}$)/1000)

To find the specific fuel consumption (work from the fuel) you need the mass fuel consumption and the mechanical power developed (measured by the Dynamometer):

$$\text{Specific Fuel Consumption} = \frac{\text{Mass Fuel Consumption} \times 3600}{\text{Mechanical Power}/1000}$$

Where:
Specific fuel consumption = kg $Kw.h^{-1}$
Mass Fuel Consumption = kg.s-1
Mechanical Power = Watts

Air/Fuel Ratio

This is simply the ratio of the air mass flow against the fuel mass flow:

$$\text{Air/Fuel Ratio} = \frac{\dot{m}_a}{\dot{m}_f}$$

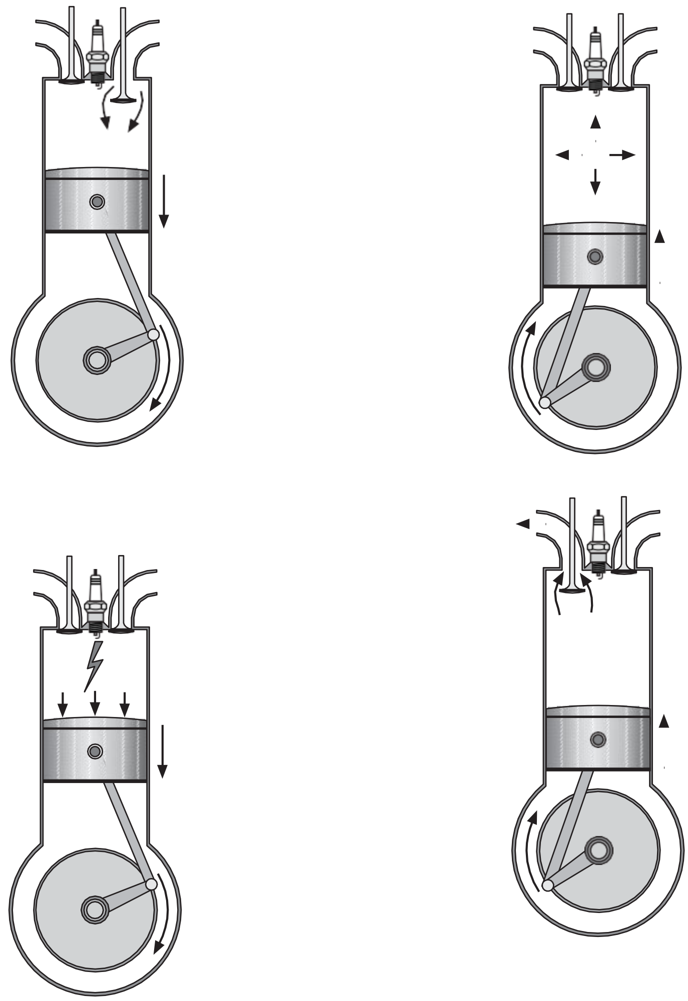
Volumetric Efficiency

The four stroke engine makes two revolutions for each swept volume of air that it uses, but the two stroke engine only rotates once for each swept volume.

The four stroke engine piston moves down to draw air/fuel mixture in, then moves up to compress and combust the mixture. It is then forced down again by the combustion and moves up to push out the exhaust gases. The four strokes are:

- Fresh Air/Fuel Mixture Drawn In
- Mixture Compressed
- Mixture Ignited
- Exhaust Pushed Out

The two stroke engine draws in fuel/air mixture and exhaust gas around its crankcase as it moves, so that each time the piston rises, it is ready for combustion.



(A)Induction

(B) Compression

(c) Power

(d)Exhaust

The Four Stroke Cycle

The volumetric efficiency is the ratio of the measured volume of air or gas that enters the engine against the calculated volume of air that the engine should use. For this, you need to know the engine capacity, the amount of engine strokes and its speed:

$$\text{Calculated Volume} = \frac{\text{Engine Capacity} \times N}{(\text{Strokes}/2) \times 60}$$

NOTE *Engine capacity is normally given in cc (cubic centimeters) or Liters. You must convert this into cubic meters for the volume calculations.*

$$100cc = .0001m^3$$

$$\text{Measured Volume} = \frac{\dot{m}_a \times R \times T_A}{p_A}$$

$$\textbf{Volumetric Efficiency, } \eta V = \frac{\textbf{Measured Volume}}{\textbf{Calculated Volume}} \times 100\%$$

Heat Energy and Enthalpy

The heat energy of combustion from the fuel (in Watts) is found by the fuel consumption and its calorific value:

$$H_f = \dot{m}_f C_L$$

The inlet air enthalpy (in Watts) is found from the air mass flow rate and the ambient temperature:

$$H_A = \dot{m}_a C_P T_A$$

Thermal Efficiency

This is the ratio of the heat energy of combustion from the fuel against the useful mechanical power developed by the engine:

$$\eta_T = \frac{\text{Mechanical Power}}{H_F} \times 100$$

Brake Mean Effective Pressure (BMEP)

This is the average mean pressure in the cylinder that would produce the measured brake output. This pressure is calculated as the uniform pressure in the cylinder as the piston rises from top to bottom of each power stroke.

The BMEP is a useful calculation to compare engines of any size.

$$BMEP = \frac{60 \text{ x Power x (Strokes/2)}}{0.1 \text{ x Speed x Engine capacity}}$$

Where:

BMEP is in bar

Power = Watts

Speed = Rev.min-1

Engine Capacity = Cubic Centimeters (cm3) or cc

Test Procedure:

Fill your Fuel Tank with the correct fuel for your Test Engine.

1. If your laboratory exhaust system includes a water (condensate) trap, make sure that it is drained before you use the Test Engine.
2. Slowly pull the starting handle of the Test Engine until you can feel that it has passed the compression stroke and is easy to turn. Allow the starting handle to return to its original position.
3. Gently rock the Dynamometer, then press the ‘Press and hold to zero’ button on the Torque and Speed display. This will zero the Torque reading.
4. Press and hold the ‘Zero airbox pressure’ button on the DPT1 Instrument Module. Release the button, the differential pressure is now zero.
5. Open both valves on the Fuel Gauge - (turn the valves so that they are in-line with the fuel pipe).

6. Make sure that fuel has passed down the fuel feed pipe to the Test Engine.

7. If you are to use TecQuipment's VDAS, make sure that your computer is operating and has started the TecQuipment software.

8. Turn on the water supply to the Dynamometer. Open the control valve by half a turn. Fully open the water outlet valve. Make sure that water flows through the Dynamometer.

Never use the Dynamometer without water passing through it. If you run the Dynamometer with no water flow, its seals may break.

9. Start and run the Test Engine as described in the engine manufacturers instructions and the TecQuipment User Guide provided with the Test Engine.

10. Allow the engine to reach normal operating temperature.

11. Set the Test Engine throttle (or rack) for maximum speed.

12. Adjust the Dynamometer control valve to increase the load on the Test Engine and decrease its speed to its lowest stable speed. You may need to slightly shut the water outlet valve and carefully adjust the Control Valve to give the best results.

13. Use the Dynamometer Control Valve to maintain the engine speed at the lowest stable speed within +/-100 rev.min-1

14. Record the test engine fuel consumption.
Shut the fuel inlet valve and use a stopwatch to measure the time taken to drain 8 mL the inlet valve before the engine is starved of fuel.

15. Record all Test Engine results as described in the Blank Results Table.

16. Use the water flow through the Dynamometer to allow the engine speed to Increase by approximately 250 rpm. Again, use the Dynamometer Control Valve to maintain this new speed and record the fuel flow and other results as Shown in the Results Table.

17. Repeat for the other speeds (up to the maximum governed engine speed) in steps of approximately 250 rpm.

Results and Analysis:

1. From your results, calculate the air mass flow rate and plot the engine variables against speed. For comparison, it is better to plot all variables on one chart or several charts of a similar scale.

   The engine variables are:

   - Engine exhaust temperature
   - Torque
   - Power
   - Air/Fuel ratio
   - Specific Fuel Consumption
   - Volumetric Efficiency
   - Thermal Efficiency
   - BMEP

2. Look at your power and efficiency curves. What is the approximate optimum performance speed for the engine?

3. Discuss the characteristic curves with diesel fuel engine having the same technical specification and conditions.

Engine			Fuel		Air and Exhaust		
Engine Speed (rpm)	Engine Torque (Nm)	Engine Power (W)	Fuel Volume (8/16/24 mL)	Fuel Drain Time (s)	Ambient Air Temperature (°C)	Exhaust Gas Temperature (°C)	Air box Differential Pressure (Pa)

Engine Speed (rpm)	Energy		Air and Fuel				Efficiency		BMEP (bar)
	Heat of Combustion (W)	Inlet Air Enthalpy (W)	Air Mass Flow Rate ($kg.s^{-1}$)	Fuel Mass Flow Rate ($kg.s^{-1}$)	Air/Fuel Ratio	Specific Fuel Consumption	Thermal Efficiency	Volumetric Efficiency	