E- Bulletin

on

Operation of FATE System in Climate Change Studies

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FATE

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OPERATION OF FATE SYSTEM IN CLIMATE CHANGE STUDIES

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Contents





Chapter 1: FATE system concept

FREE AIR TEMPERATURE ENRICHMENT (FATE)is developed to artificially induce canopy temperature under open air conditions without the use of any casing. The FATE system simulates global warming, but in a small ecosystem of limited size with the disability of thermal radiation and canopy temperature through the plot. This system is based on a series of microcomputer-controlled systems for an effective control of temperature and CO_2 concentration in the open air. The FATE system can simulate CO_2 and temperature enrichment conditions and a variety of research experiments can be carried out to capture the impacts of elevated CO_2 and temperature on crop performance.

In the FATE system, CO_2-enriched air is injected around the perimeter of circular plots and the natural wind spreads CO_2 through the experimental area freely around the rings. We have nine rings where elevated CO_2 (e-CO_2), elevated temperature (e - Temp) and a combination of both (e-CO_2+ *e*-Temp) are maintained independently (Figure 1) in the rings in order to accurately quantify the individual and combined impacts on crop growth.

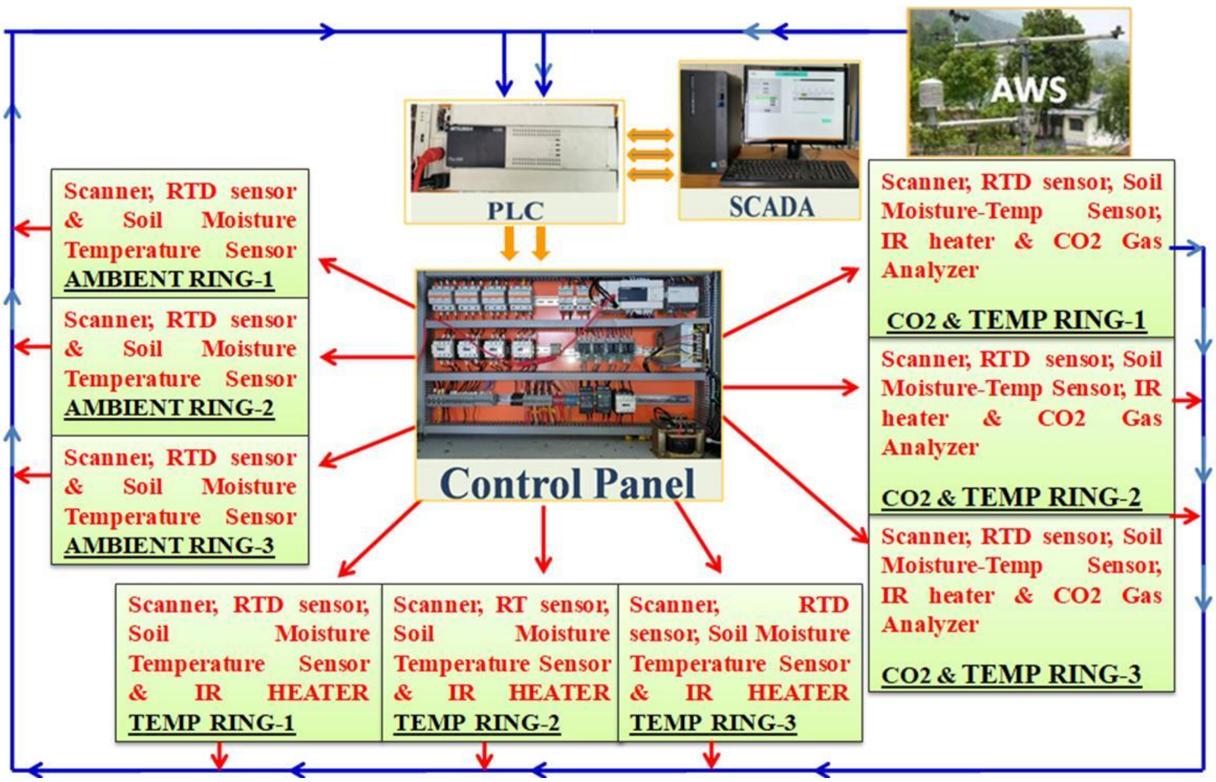


Fig. 1. The concept of FATE system

i). Structure: The FATE system consists of 8 m diameter rings surrounded by steel poles to support the infrared heaters (IR Heaters) (1 kilowatt; 220 volts). Weather-resistant IR heaters are positioned at an angle of 40° and approximately 1.2 m above ground level. These infrared heaters are made from tungsten filament and can radiate at 2000°C into rings at elevated temperature. Each ring is equipped with a Resistance

Temperature Detector (RTD) sensor (Pt-100) (Figure1) to monitor the temperature as well as soil moisture and soil temperature sensors.

The sensors of the FATE rings are connected to the Scanner (Analogue Input Module, AIM) which dispatches the parameters (temperature & CO_2 concentration) data to SCADA (Supervisory Control and Data Acquisition**)** via a PLC (Programming Logical Controller) (Figure1). These sensors control output loads like infrared heaters and CO_2 gas analyzer and solenoid valves. All data on temperature and CO_2 concentration in the FATE rings are monitored individually by a dedicated supervisor - computer using SCADA software.

ii). Sensing

a) Temperature: Each experimental ring of the FATE facility is equipped with several sensors such as an RDT sensor (Resistance Temperature Detector, Type: Pt-100), soil moisture-temperature (Make: BONAD), and a high-precision scanner (Analogue Input Module, Radix-SCM 201). These electronic devices are being monitored and controlled by the SCADA through the PLC to maintain an elevated temperature of 3.0 ± 0.5°C on the reference experimental ambient rings. RTD sensors measure a temperature range from 0 to 100°C with 0.5°C accuracy and 0.02% resolution. To maintain the canopy temperature in the elevated temperature rings, twenty-four numbers (24 numbers) of infrared heaters (1 kW each, 230V) in each ring have been installed on erecting poles which are adjustable to crop height.

b) Carbon dioxide: In CO_2 controlled experimental rings, CO_2 gas is monitored by the microprocessor based CO_2analyzer with Non-Dispersive Infrared (NDIR) absorption measuring method. The accuracy of the CO_2 analyzer is ±0.5% at full scale and the response time is 1 to 3 seconds; with 1% linearity; 0.5% of the full scale noise. To measure the CO_2 concentration in each ring, four (4) automated sampling points or filters equipped with a CO_2 gas analyzer interfaced with SCADA and PLC are installed. For CO_2 control, a direct-acting solenoid valve (220V AC) is supplied with an accuracy of 30 ppm and a scale from 0 to 2000 ppm.

iii). Maintenance of temperature gradient: Since the FATE facility is an open-structure, facility, the elevated temperature (e.g. 3° ± 0.5°C over ambient temperature in our case) is maintained by first comparing the ambient/reference temperature for each of the ambient rings. Then, on the three reference temperatures of the three separate ambient rings, the highest reference temperature is chosen. For instance, the highest reference temperature of the ambient rings is selected (e.g. 25° C at Umiam) plus an elevation of 3°±0.5°C. Therefore, a high temperature (28° ± 0.5°C) is maintained within each elevated temperature ring.

iv). Control through PLC (Programming Logical Controller): A PLC system is used to analyze, check and maintain the desired set of CO_2 concentrations (for example 550± 50 ppm at Umiam) and the elevated temperature conditions of 3°C ± 0.5°C in the respective experimental rings.

PLC is installed to monitor the sensors and to collect data, receive critical information on the flow and entry into the system. It carries out basic interventions such as triggering outputs when the parameters programmed in the system are reached (e.g.

Temperature, relative humidity, gas concentration, etc.).The PLC system receives and reads the input signals with the help of scanners and immediately updates the output by sending the signal to the SCADA software. The SCADA initiates the operation of specific equipment/ sensors/ IR heaters in the rings.

The operating mechanism of the PLC-CPU is listed in the flow chart (Figure 2) as

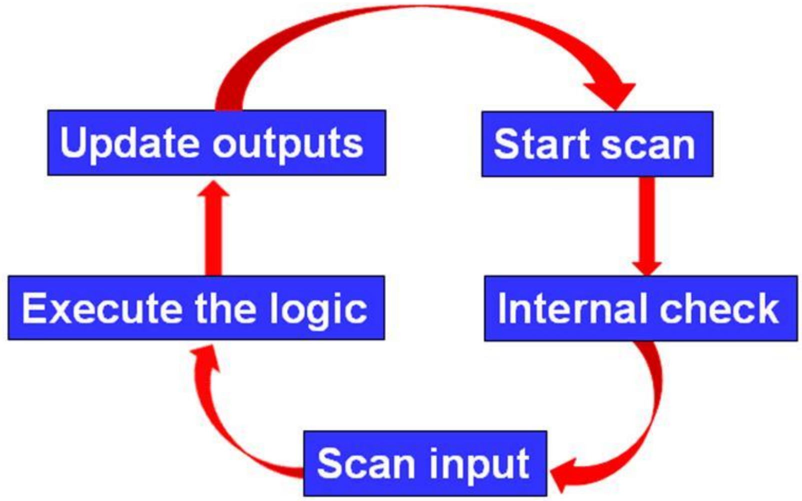


Fig.2. CPU Operating Cycle in PLC

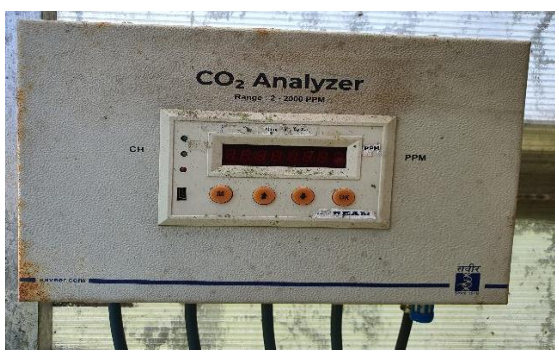
1.1 Different integral parts of working instruments, sensors for fate:

The FATE system employs the following sensors/instruments

a) IR Heaters (Infrared Heaters): The IR heaters artificially induce heat for maintaining the canopy temperature at the desired level of elevated temperatures, which is controlled by the SCADA software.

(IR Heater)

b) CO_2 Gas Sensor: It scans and analyzes the CO_2 gas concentration inside the elevated CO_2 rings.



CO_2 Gas Analyzer **CO_2 Gas sampling point**

c) CO_2 solenoid valves: For controlled spraying of the CO_2 gas to the elevated CO_2 FATE rings according to the wind direction sensed by wind direction sensor.

(CO_2 solenoid valve)

d) Resistance Temperature Detector (RTD) sensor: Sensor for sensing/detecting the temperature of the rings.

(RTD Sensor)

e) Soil Moisture & Soil Temperature sensor: They detect/ sense the moisture and temperature of the soil inside the experimental FATE rings.

(Soil moisture and temp. sensors)

f) Analogue input module (AIM scanner): It is an electronic device for reading the real-time data from the sensors like RTD sensor (Pt-100), soil temperature-soil moisture sensors, and other electric instruments, thereby dispatching the data into the SCADA software through the PLC (Programming Logic Controller).

(Analogue Input Module Scanner)

1.2. AUTOMATED WEATHER STATION

FATE also has a dedicated automated weather station (Figure 3) for monitoring all the weather parameters: air temperature, relative humidity, wind direction sensor, rainfall sensor, solar radiation sensor, and wind speed sensor. These sensors are made by Virtual Electronics Company, an expertise in manufacturing the automated weather stations.

a) **Wind Direction sensor**: the electronic wind vane represents the latest technology in wind direction detection. It is a balanced wind direction vane with a near zero-friction bearing and a high accuracy magnetic angle sensor to provide precision wind direction. Its unique feature is that it easily sets ‘North’ regardless of any mounting orientation. The model used is SEN-WD; range is 360 degrees; accuracy is ± 0.3 and a signal range of 50±0.5%.

b) **Rainfall sensor:** the sensor used is tipping-bucket rain gauge for measuring rainfall and has the size of 8-inch diameter collector which meets the IMD specifications for statistical accuracy. Each time a drop of rain drips on the bucket tip, a pulse is transmitted and each pulse shows a 0.20 mm of rainfall. The range is 100 mm per hour and accuracy is 5% for 25 mm per hour.

c) **Solar radiation sensor**: this is a self-powered sensor with a milli-volt output and exhibits excellent cosine response which incorporates a silicon-cell photodiode measuring total shortwave, radiation with a sensor housing design that features a fully potted, domed-shaped head making the sensor fully weather proof and self- cleaning. It is an important component to determine the evapo-transpiration rates, net radiation, etc. The model used is SEN-SR-SW; the sensitivity is 0.20 mV per Wm^{-2}.

d) **Wind speed sensor:** this sensor is a 3-cup Anemometer, a traditional type sensitive to horizontal wind speed measurement. It is constructed with a light-weight and UV resistant plastic cups. The model used is SEN-WS; accuracy is 0.5 m/s and resolution is 0.1 m/s. The speed range is 0.5 m/s to 67 m/s.

e) **Temperature humidity sensor:** this sensor is used for measuring both the temperature and humidity of the ambient surroundings. It is protected by a radiation shield and hydrophobic filter to avoid the condensation and dust over sensor. The model used is SEN-TH. The temperature range is - 40° C to 123° C; accuracy is ±0.1º C @ 0.01º C. The relative humidity range is 0-100% RH; accuracy is ±2 % RH @ 0.5 % RH.

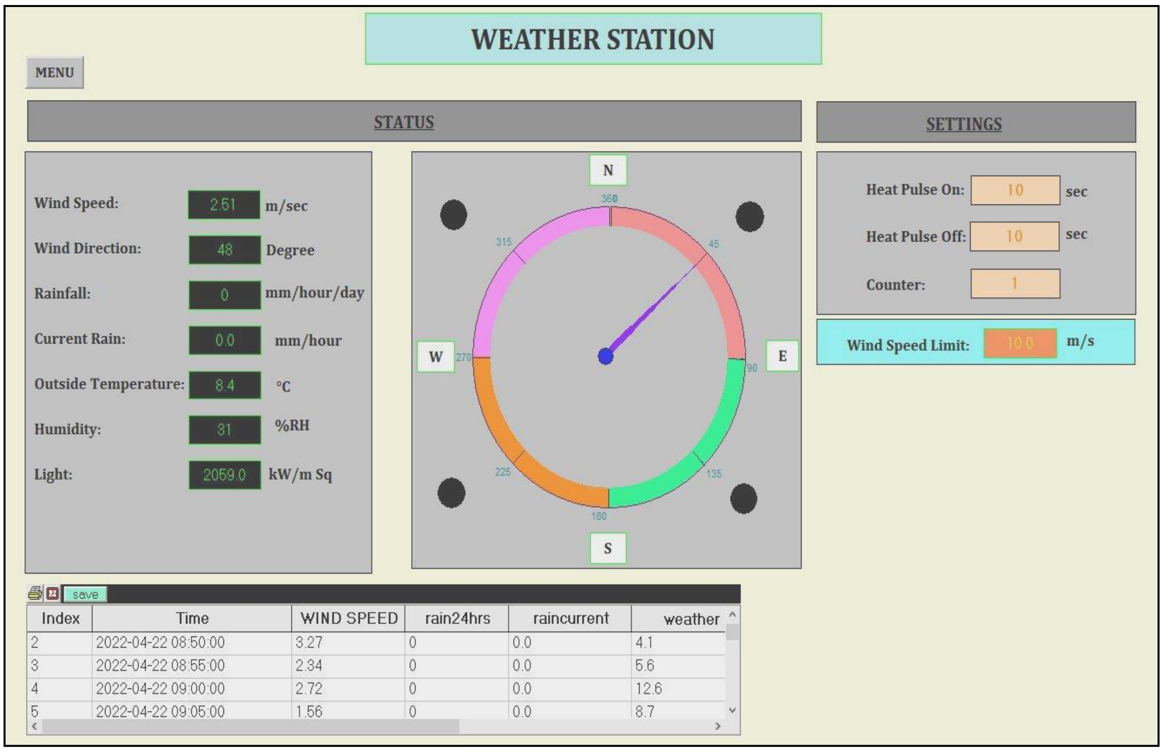
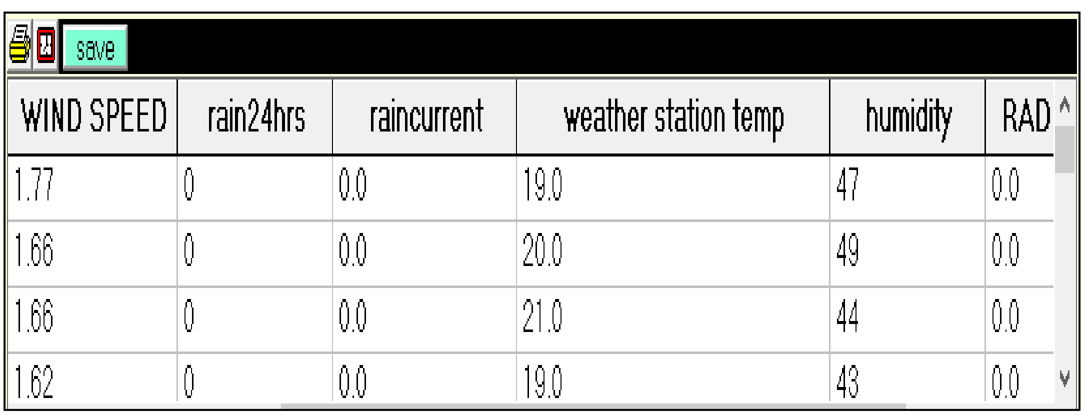


Fig. 3. The status of weather station from SCADA



WIND SPEED	rain24hrs	raincurrent	weather station temp	humidity	RAD
1.77	0	0.0	19.0	47	0.0
1.66	0	0.0	20.0	49	0.0
1.66	0	0.0	21.0	44	0.0
1.62	0	0.0	19.0	43	0.0

Fig. 4. The data of weather parameters in weather station in SCADA

Chapter 2: FATE- Configuration

The FATE installation at ICAR RC for NEH, Umiam has nine (9) experimental rings, each of the three (3) rings have an ambient, elevated temperature, and a combined elevated temperature and elevated CO_2 gas concentration provisions. The rings were maintained independently and equipped with IR heaters with the provision for height adjustments with respect to the crop. Each ring has a diameter of eight meters (8 m), equipped with a water hose and a water tap for appropriate irrigation of the experimental crops grown inside and has a proper drainage system to remove excess water from the rings. In addition, in the elevated CO_2 rings, CO_2 enriched air is injected around the perimeter of the circular rings, where the natural wind freely disperses the CO_2 gas in the experimental zone without any interference, e.g. Trees, walls or any other kind of obstacle appears around the circumference of the rings.

All the nine (9) experimental rings are separated from each other by a distance of fifteen meters (15 m) apart while thirty-two meters (32 m) apart between the elevated CO_2 rings. The structures of the experimental rings of different conditions in FATE facility are as shown below:

1. **Ambient Ring**: The structure of an 'Ambient' Ringwith the equipped sensors/IR heater is shown below (Figure 5),
   - RTD (Resistance Temperature Detector) sensor (1 no.)
   - Scanner (Analogue input module) (1 no.)
   - Soil Temperature & Moisture sensor (1 no.)

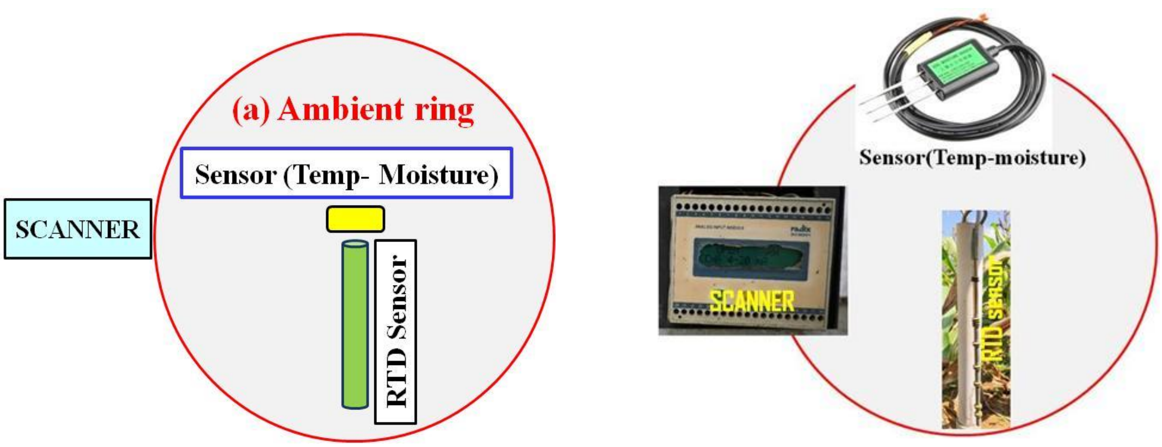


Fig. 5.Graphical representation and actual structure of the"Ambient ring"

2. **Elevated Temperature Ring**: The structure of an 'Elevated Temperature 'Ring is shown below in the figure (Figure 6), the sensors/heaters used includes:
   - RTD (Resistance Temperature Detector) sensor (1 no.)
   - Scanner (Analogue input module) (1 no.)
   - Soil Temperature & Moisture sensor (1 no.)
   - IR Heaters (Infrared Heater) (24 nos.)

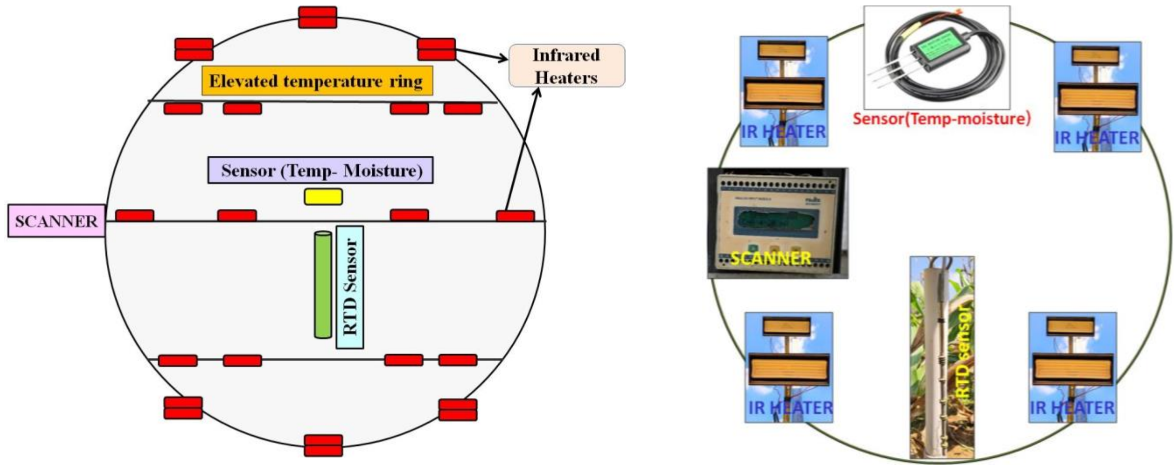


Fig. 6.Graphical representation and actual structure of the "Elevated temperature ring".

3.Elevated CO_2 plus elevated temperature ring: The structure of an 'Elevated CO_2 plus elevated temperature' ring is shown below in the figure (Figure 7), some of the sensors/equipments/instruments used are the same with Figure 6 while the additional ones to regulate CO_2 flow are as follows:

- CO_2 gas valves (4 nos.)
- CO_2 gas analyzer (1 no.) & CO_2 gas filter sampling point (4 nos.)

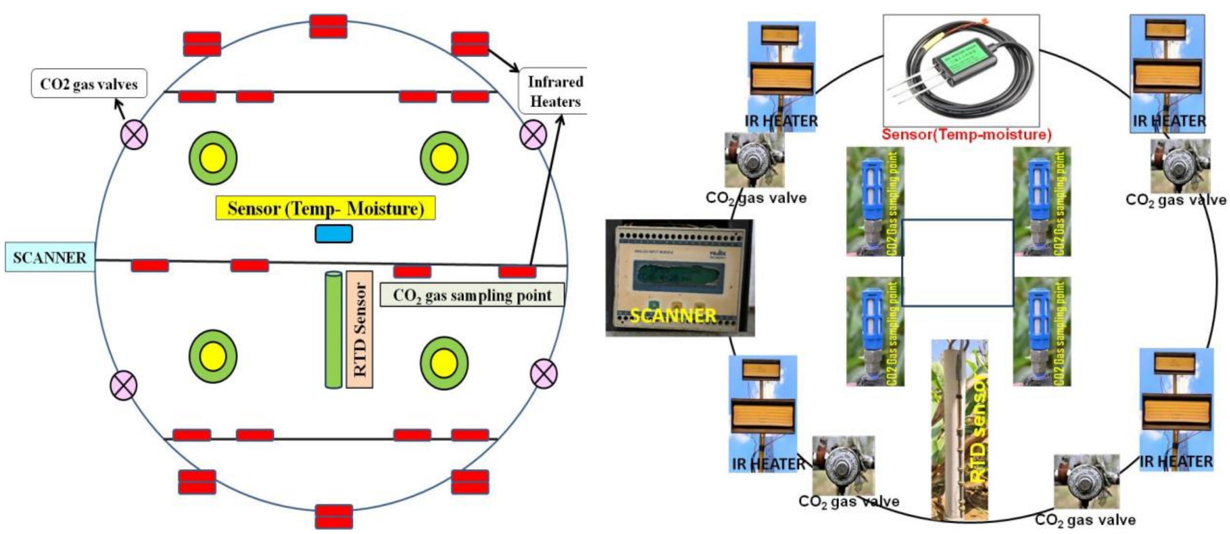


Fig. 7. Graphical representation and actual structure of the "Elevated temperature plus elevated CO_2 ring".

Chapter 3: FATE-the experimental set-up

Collectively, there are 9 (nine) rings in FATE facility where each of the ring has different control conditions while maintaining a replication for the other rings. For better understanding of the arrangement and set-up of the experimental rings inside the facility, the following has been considered:

1. FATE rings in ambient control condition: In these three (03) rings, only the ambient conditions like ambient temperature and ambient carbon-di-oxide gas (CO_2) from the surrounding are being maintained and research experiments are conducted under these conditions only, representing natural environmental condition (**Fig. 8**).

In the ambient rings: Only RTD (Resistance Temperature Detector) and STMS (Soil Temperature -Moisture Sensor) along with Scanner (Analogue input module, AIM) are fitted.

Fig. 8. Ambient Rings (without IR heaters and CO_2 Sampling points)

2. Three (03) rings for maintaining elevated temperature (3°C ± 0.5°C):

In these three (03) rings, temperature is elevated by +3°C from the surrounding including ambient rings while the CO_2 gas is equal to surrounding. The infrared heaters (IR heaters) are used for maintaining the canopy temperature inside the experimental rings (Figure 9). Like the sensors used in the ambient rings, here in the elevated temperature rings, the only additional instruments are the 24 nos. of Infrared heaters (IR heaters), each one has one kilowatt capacity, is used for maintaining the elevated canopy temperature inside the rings.

Fig.9. Elevated Temperature Rings (without CO_2 gas sampling point)

3. Three (03) rings for maintaining elevated temperature (3°C ± 0.5°C) and elevated CO_2 gas (550 ppm ± 50 ppm):

In these three (03) rings, both the temperature and CO_2gas are set at elevated conditions i.e. at (3°±0.5° C) and (550 ppm ± 50 ppm) (Figure 10). The experimental crops grown in these rings are subjected to these controlled elevated environmental conditions. The CO_2 gas analyzer together with CO_2 gas sampling points analyze and send the data to the SCADA software through the PLC, which then activates the CO_2 solenoid valves to spray the desired quantity of CO_2 gas to the set concentration of 550 ppm. The CO_2 gas is sprayed along the wind direction as sensed by the wind direction sensor from the SCADA.

In the elevated temperature plus elevated CO_2rings, apart from the 24 nos. of Infrared heaters (IR heaters) as described (in point 2), the additional sensors/ instruments used in these rings are the CO_2 gas analyzer with CO_2 gas sampling points and the solenoid valves for the spraying of the CO_2 gas for uniform concentration inside the rings.

Fig. 10.Elevated CO_2 and elevated temperature rings

Chapter 4: FATE-the integration of parts

i). PLC (Programming Logical Controller): PLC is an industrial computer specially developed and adapted for automation system, processing and is programmed to control machine operations for any activity that requires high reliability, ease of programming, and process fault diagnosis.

A PLC is installed to monitor sensors and for data collection, receiving critical information about the flow and input within the system. To this end, the PLC will perform basic interventions, triggering outputs when the parameters programmed into the system are achieved (e.g. Temperature, relative humidity, gas concentration, etc.). It also consists of various input terminals, where it monitors the status of the switches, devices, and output terminals. Based on their status, it will command to the output devices through the output terminals (Figure 11).

PLC incorporates power supply, electrical switches, and other safety accessories (electrical relays, mechanical relays), CPU, and I/Os into a single compact unit. Its I/O is connected in connector format, reducing wiring effort. FX3U can count at high speed input frequency of 100 kHz (1-phase 6 pts), 50 kHz (2-phase 2 pts), 10 kHz (1-phase 2 pts). This particular PLC used in FATE system is made by Mitsubishi brand (model: MELSEC-F).

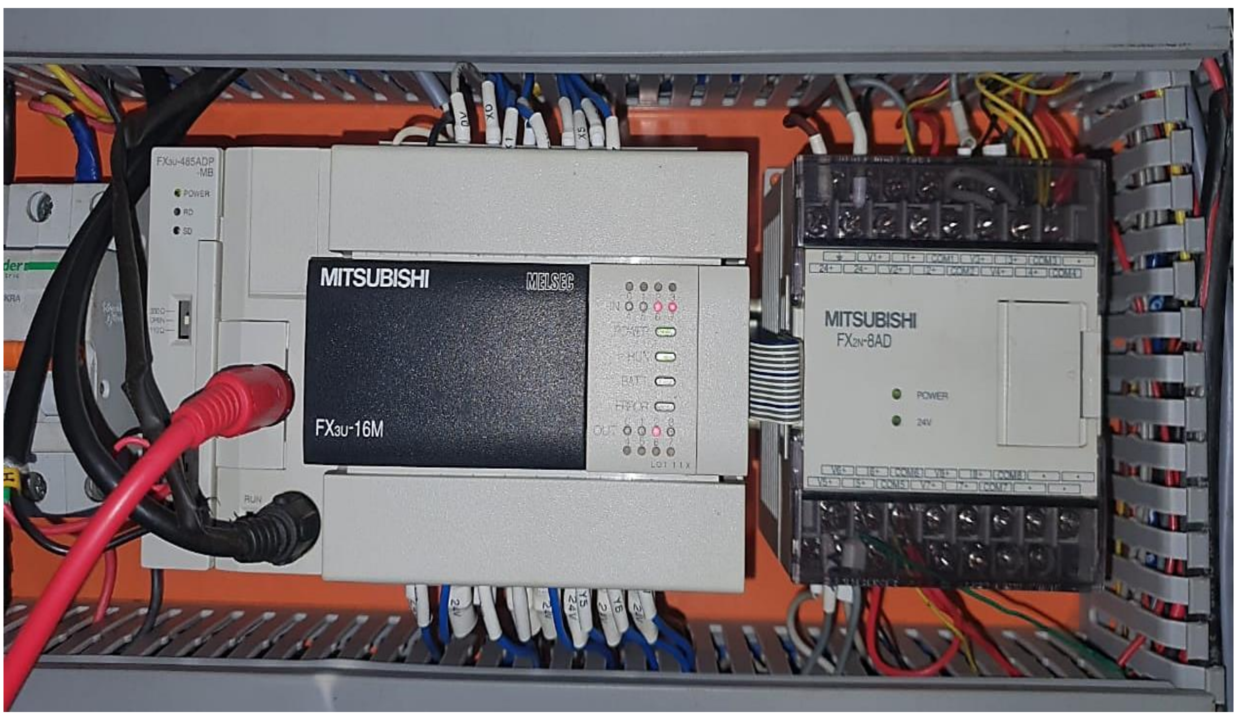


Fig.11.The PLC (Programming Logical Controller)

ii). SCADA (Supervisory Control and Data Acquisition) system:

A supervisory computer is the core of the SCADA system, which collects experimental data of all the nine experimental rings on the process or status (e.g. Temperature, CO_2 gas concentration) and sends respective control commands to the connected devices such as IR heaters, gas analysers, RTD sensor, and analogue input module. Generally, SCADA is completely a software package (Figure 12) that helps to monitor the entire automated process. SCADA mainly does three operations such as (a) supervising real-time data in the form of graphical presentation, (b) controlling automated processes through remote locations, and (c) acquiring real-time data as well as logs data into the supervisory computer.

The SCADA software processes, distributes, and display the data on the control monitor. Few systematic steps SCADA follows as below

- Data acquisition begins at the PLC level which includes instrumentation, readings, and equipment status/reports that are communicated to SCADA and those data is then compiled and formatted in such a way that a control room operator using the HMI (Human Machine Interface) can make supervisory decisions to adjust or override normal PLC controls.
- The supervisory computer is connected via a USB to serial link to the PLC. The SCADA program has a user configured database which provides the software about the connected instrumentation and parameters which are to be accessed (in our case, the desired parameters are temperature and CO_2 gas concentration).
- The database also has information on how often the parameters of the instruments are accessed and if a parameter is a read only value (e.g. a measured value) or read/write, allowing the operator to change a value (set point).
- The SCADA software continuously updates its own database with the latest analogue while functioning. The digital values collected from the PLC allow real time calculations to be made on the received data and the results would be available as a “virtual” value.

Relationship between PLC and SCADA:

Both PLC and SCADA software are used in all automation processes and they collectively work together for a safe and efficient operation. SCADA can be viewed at as the broad software structure that supports the entire system while PLCs are a part of the system that SCADA oversees. The PLC depends on SCADA to control their function, but SCADA relies on data from the PLC to complete its overview.

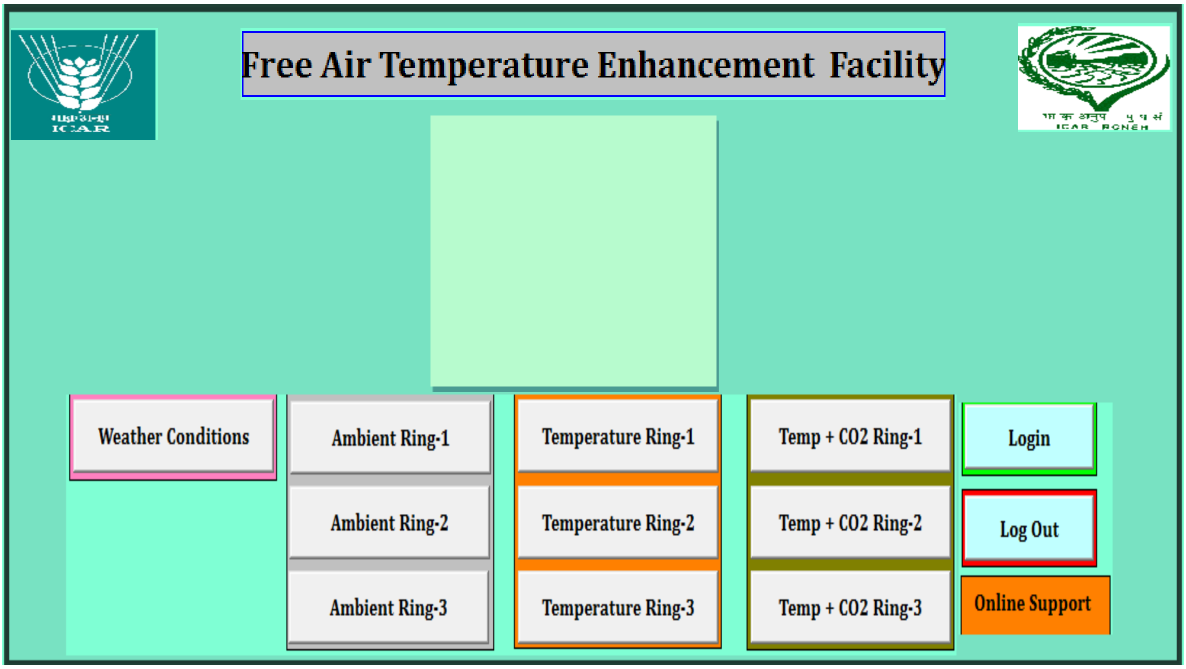


Fig. 12.SCADA software in FATE

iii). Analogue input module/ scanner:

A device that measures more than one reading points or multi-channel and displays signals of each channel one-by-one up to last channel and then returns to first channel and continues in a cyclic process (Figure 13). This continuous cyclic process of measurement is called scanning. In FATE facility, the input values or data of temperature, CO_2 gas concentration, soil moisture and soil temperature measured by each sensor are being scanned by scanner for sending to SCADA via PLC.

Specifications:

The Analogue Input Module employed in this facility is Radix SCM201 which acts a system integrator for PLCs and SCADA. This module has 8 input channel where each channel has a universal input - 8 thermocouples, RTD Pt-100, 0/4~20mA and 0~50mV can be user programmable.

For communication, it has an isolated RS485 / MODBUS RTU port and has inbuilt SMPS for 85 to 265 VAC, 50/60 Hz field supply conditions. Its 2x16 backlit LCD allows all important data to be viewed at field with 3 keys, 3 levels of programming.

Fig. 13. Analogue Input module- Scanner (Radix- SCM 201)

iv). Switching unit panel: All the nine (9) experimental rings have independent switching unit panels. This switching panel has a metal enclosure designed to work in high temperature and high humidity conditions. It receives the electrical signals from PLC and accordingly, it runs the output equipments like IR heaters for heating, CO_2solenoid valves for spraying of CO_2 gas. Switching panels has suitable electrical contractors, electrical relays, and other safety electrical devices. Some of the electrical components inside the switching unit panel comprise the following:

Electromagnetic induction relays: Relays are electrically operated switch that opens/closes the circuits on receiving electrical signal by the effect of electro-magnetism for operating a mechanical switching mechanism (Figure 14).

Solid-state (SS) relays: Unlike electromagnetic induction relays, solid- state relays have no moving parts (Figure 14).They are sealed in a plastic case and effective against dirt, dust, and humidity/moisture. They contain LEDs, transistors, etc. and are effectively used to control large AC (Alternating Current)/ DC (Direct Current) loads.

Hybrid Relays: The input circuit of this relay is an electronic circuit while the switching action is mechanical. Used in applications where power isolation between output and input is required with the Solid- state (SS) relay.

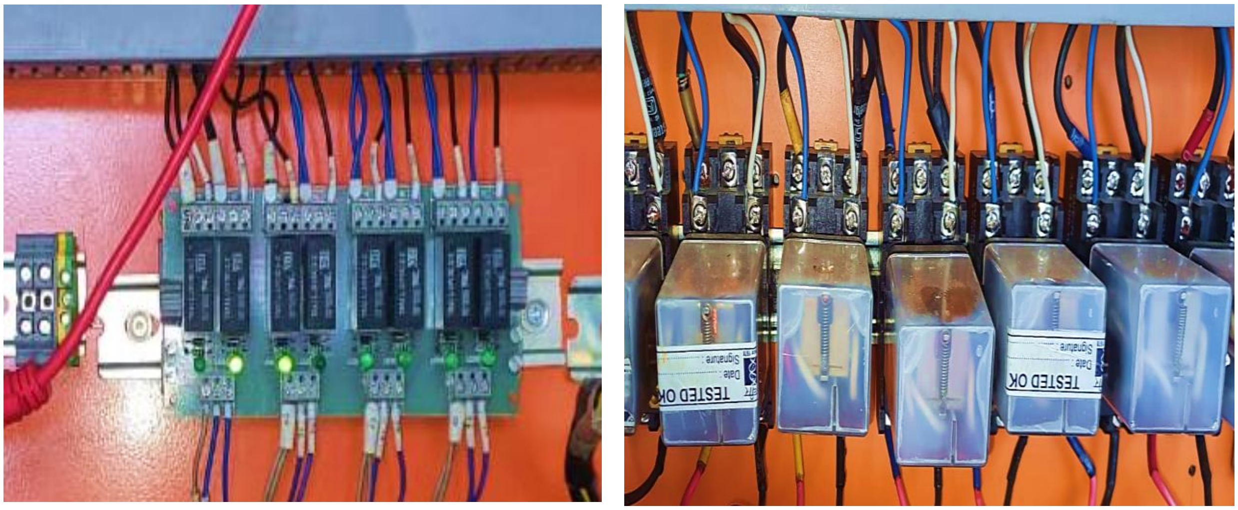


Fig. 14. (L) Solid-state (SS) relays; (R) Electromagnetic induction relays

Single Phasing Preventer (SPP, model: SM 301, 3 Phase, 415 VAC): This device is used for protection, burnouts, and faults in line to monitor and regulate the phase unbalance and negative phase sequence (Figure 15).

Automatic Voltage Relay (model: SM-500 MD71B9): This relay automatically regulates the voltage, protects against phase loss, phase-reversal, and phase-phase unbalance (Figure 15).

Contactors (Model; LC1D18): A large electrical relay usually used for repeatedly establishing and interrupting an electric circuit under normal loads. It switches current to a higher power load such as an electric motor/ pumps to prevent the devices from over-current damage (Figure 15).

Fig. 15. (L) Single Phasing Preventer & Auto-Voltage Relay; (R) Contactors

Main Switch Fuse/ Main Line Fuse (200A, 415V, 50 Hz): This switch's function is to disconnect the power supply of FATE control panel from the main line (3 phases, 440V) in case of any electrical faults, emergency repairing, and other safety purposes (Figures 16-17).

Fig.16. Left: Main Line panel & Right: Main Switch Fuse

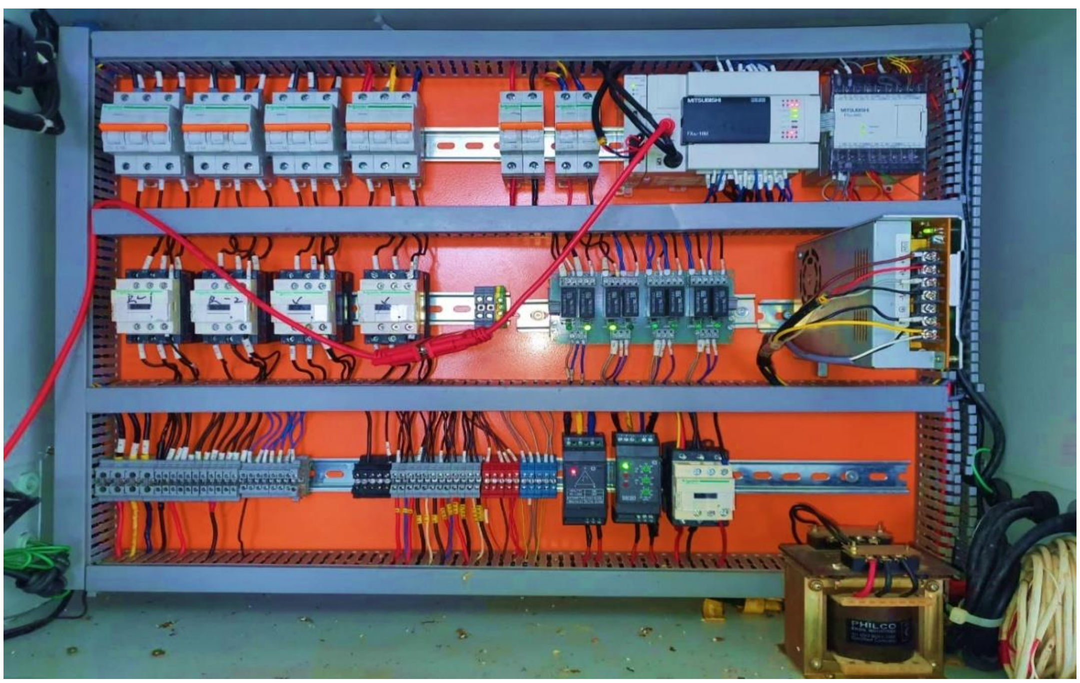


Fig. 17.FATE Control Panel

v). Monitoring of FATE:

Data monitoring and data management is done with the help of a high-specs computer, serving as a human machine interface (HMI) with high-end SCADA software. HMI (Human Machine Interface) is a device or software that is used to communicate with the machines, sensors, and electrical instruments in the automated.

Human Machine Interface (HMI) is mainly used for (a) to monitor or visualize the entire process, and (b) to control the process. MI may come in the form of the built-in screen on machines, computers, tablets, etc. performing the same purpose. The real time data of all the nine (9) experimental rings are displayed in the SCADA software, thereby, allowing the operator to monitor the data continuously through the HMI or the supervisory computer. In the software, the status of IR heaters, solenoid valve, and other connecting output equipments can be known. It also acts as a data grid so that we can access all past data over graphical format or excel sheet.

vi). Data control / processing unit in FATE system:

Data management system for SCADA and PLC includes computer system with the following specifications:

- Monitor 21.5” LED with red eye protection feature
- Operating system: 32-bit windows 7 professional with licensed key and original CD, Intel CoreTM i3-4150 CPU @ 3.50 GHz
- 500 GB SATA hard disk drive (7200 rpm), DVD writer, MS office 2007, Multimedia graphic card.
- Ram size: 4GB DDR3, 32 bit, 4 DIMM sockets for memory slots, 4 nos. of bays (2 nos. 5.25” for optical media drives and 2 nos. 3.5” for hard disk drives).

Chapter 5: Operation of the FATE facility

5.1. Control panel: It works in the following steps

Step I: First, switch on the power from the main line panel/ switch fuse unit and then the MCB for powering the control panel and Chiller (as shown in the Figure 18).

Fig. 18. (L)main line panel; (R)MCB for powering the control panel

Step II: Note that the automatic relay and supply monitoring phase/ single phase preventer (Figure 19) must be powered i.e. LED must be displayed to signal that the phase and power are in safety operating condition. In case of automatic relay displays

- Green LED, that means stable voltage i.e. 415V for 3-phases& 240V for single phase. This signifies the voltage is suitable for operation. If it is in
- Red LED, that means may be Over-voltage (OV) or Under-voltage (UV). This signifies that the voltage is unsuitable for operation.

Fig. 19. Automatic relay (L) and Supply monitoring phase (R)

In the case of supply monitoring phase, it has the following functions:

- Healthy/ Suitable voltage: LED is displayed 'ON'
- Phase loss: LED is not displayed i.e. 'OFF'
- Phase asymmetry: Fast blinking of LED
- Sequential Fault: Slow blinking of LED

These devices are crucial whereby any fault arises in each of these two electrical devices; the facility would not able to operate.

Step III: Insert the UPS plug into the power switch and turn on the UPS unit to power the PC and other electrical panels and electronic devices (Figure 20).

Fig. 20. UPS unit connected to a power source.

Step IV): Switch on all the four MCBs for powering the four electrical contactors (as shown in figure 21). This action will then power the solid state relays.

Fig. 21. Four MCBs for powering the four electrical contactors

Step V): All the MCBs of the IR heaters and CO_2 solenoid valves (as shown in the Figure 22) in the experimental rings must be switched on.

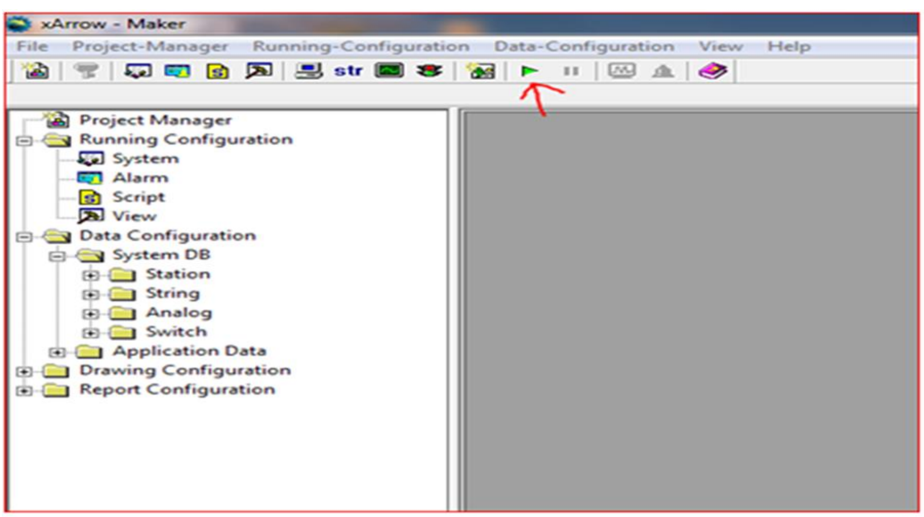
Fig. 22. (L) The MCBs of the IR heaters and (R) CO_2 solenoid valves

5.2. SCADA Software: How it works are listed below

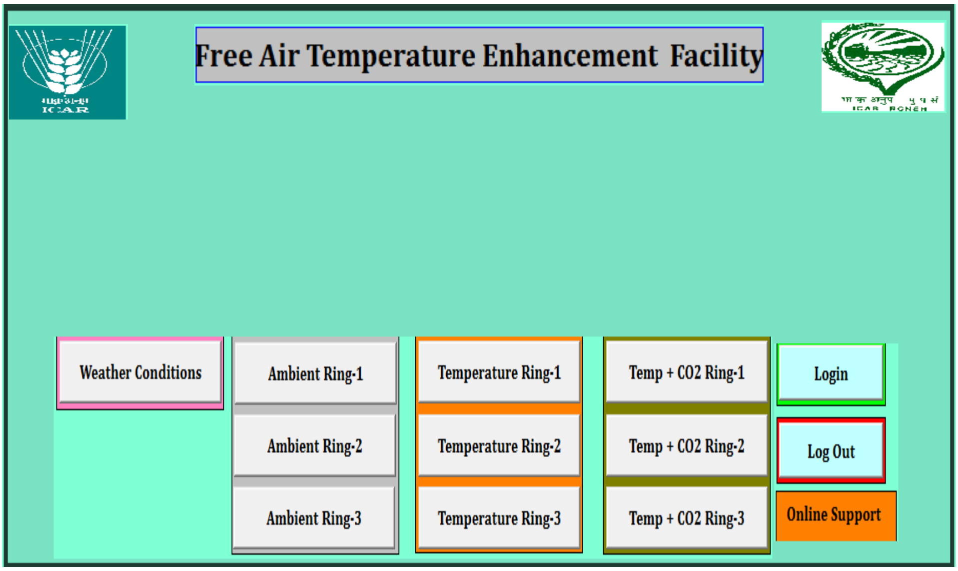
Step I: Click on the SCADA icon on the PC desktop to run SCADA software (xArrow-Maker) in the computer desktop (Figure 23). Wait for 2-3 seconds for loading.

Fig. 23. SCADA software icon on the desktop

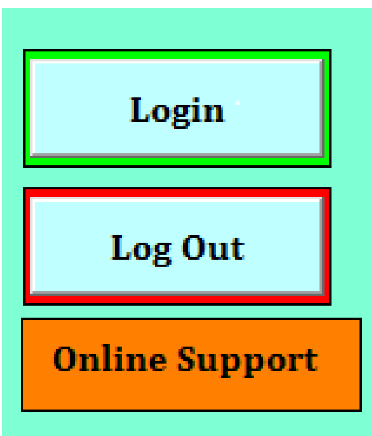
Step II: Wait for 2-3 seconds as the SCADA software is still loading for display. Then click the '**green play button'** to open the SCADA page (as shown below).

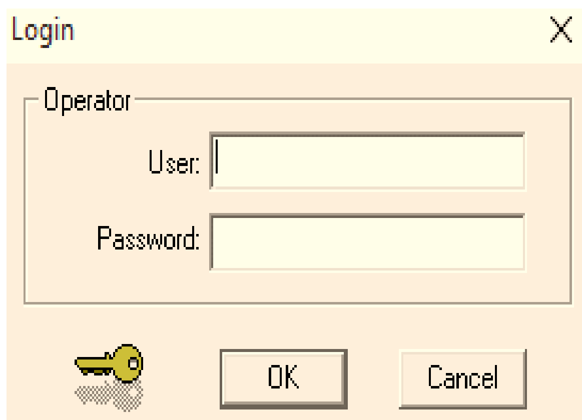


Step III): A display like 'Initialize script interpreter…' will be shown after which the SCADA main status/ setting page will appear as depicted in the following screen.



Step IV): Login using the set User ID and password to gain access for control and monitoring of FATE facility through SCADA.





Step V): Choose the highest reference temperature from any of the three ambient rings by clicking the 'enable/disable option' to set the reference temperature (Figure 24). Accordingly, the reference temperature from each ambient ring is selected (e.g. 25°C) plus a 3° ± 0.5°C rise. Thus, an elevated temperature of (28°± 0.5°C) in each elevated temperature rings is maintained (Figure 25).

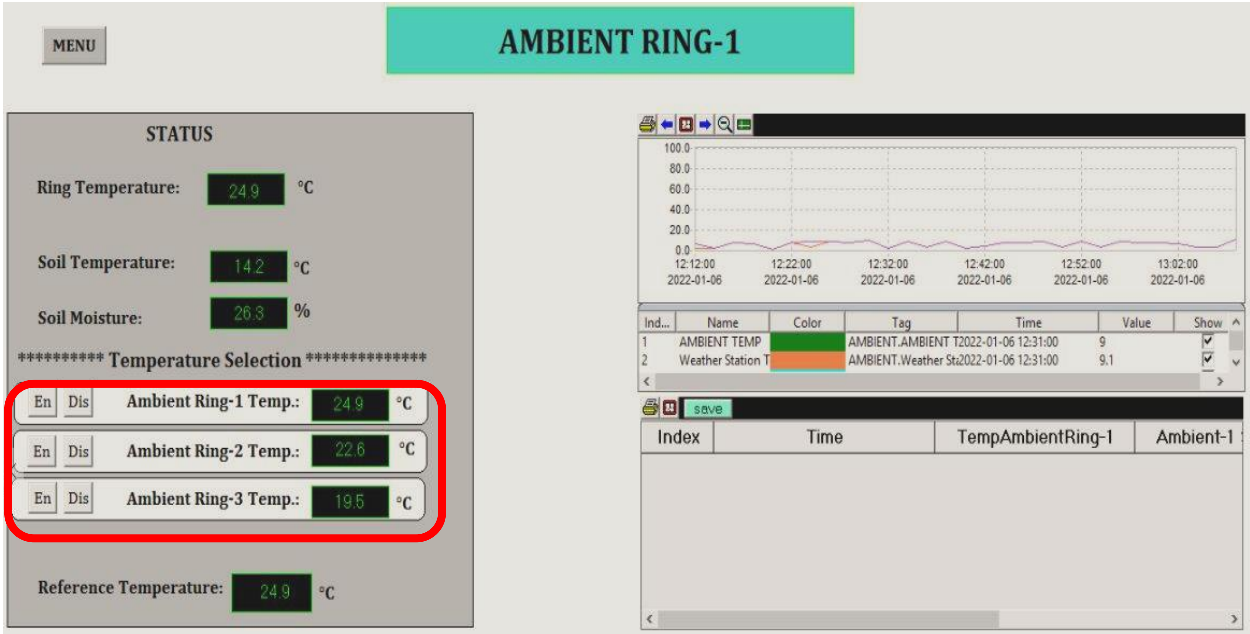


Fig.24. Status of ambient ring

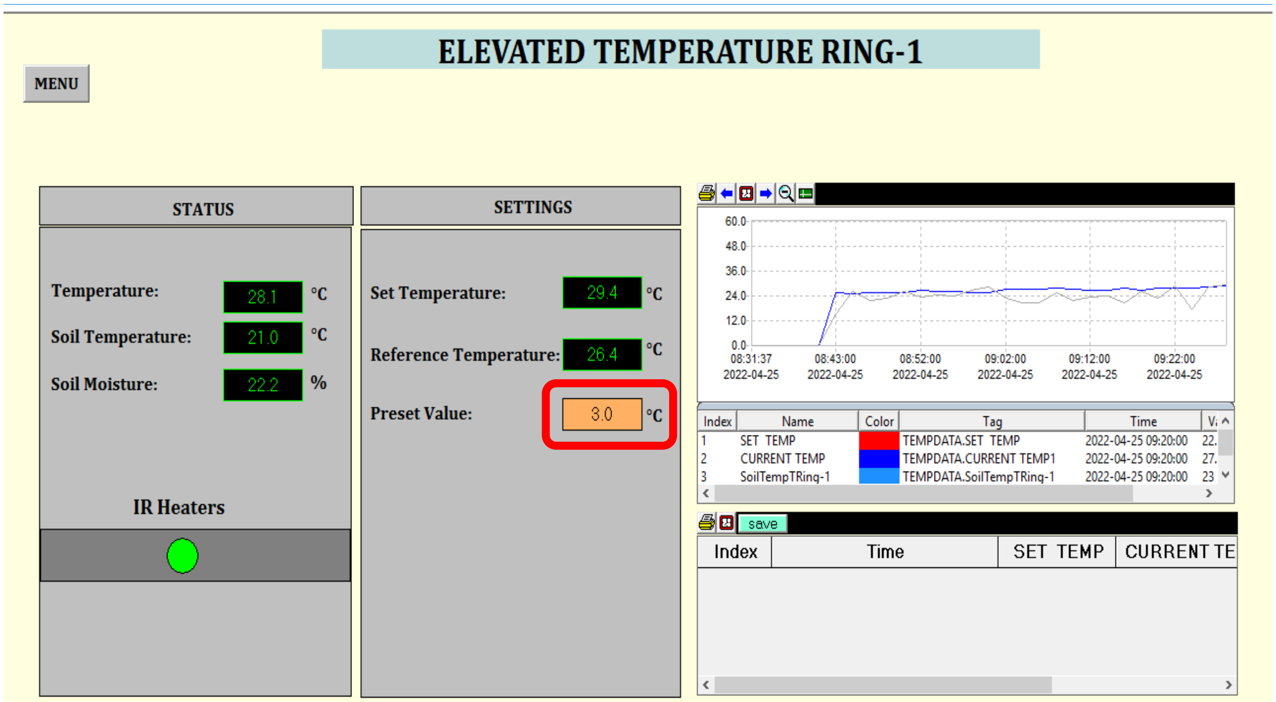


Fig. 25.Status of elevated temperature ring

- Also, the same elevated temperature (3°C ± 0.5°C) and elevated CO_2 gas concentration of 550 ± 50 ppm is maintained in the elevated CO_2 rings (Figure 26). As seen from the figure, the status of CO_2 gas concentration in SCADA software is 420ppm, while the set CO_2 gas concentration is 550ppm. Therefore, in order to maintain the desired concentration, the CO_2 gas solenoid valves are switched on (displayed as green) to increase the CO_2 gas concentration in the FATE up to the set point.

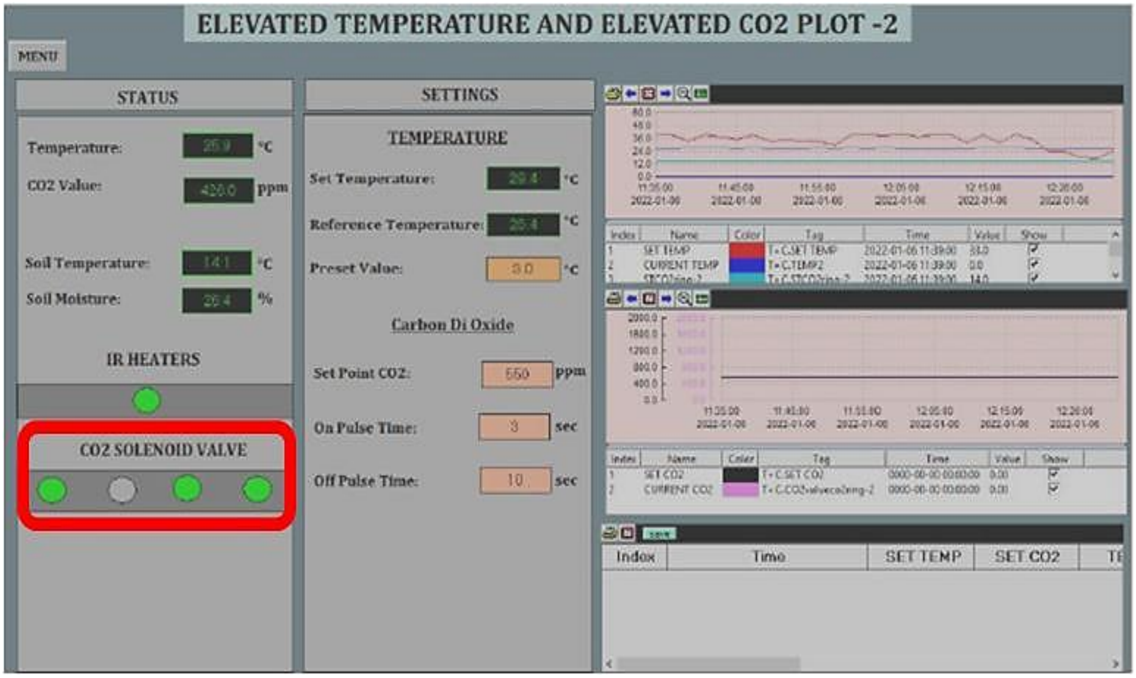


Fig. 26.Status of elevated temperature-elevated CO_2 ring

5.3. Database management

Step I): On the right hand side of the status page, an option '**Query**' is present for presenting the data that was saved and monitored by SCADA during the operation of the facility. This option is also to retrieve the recorded data desired to be saved. The simple procedure is as shown in the below figure (Figure 27).

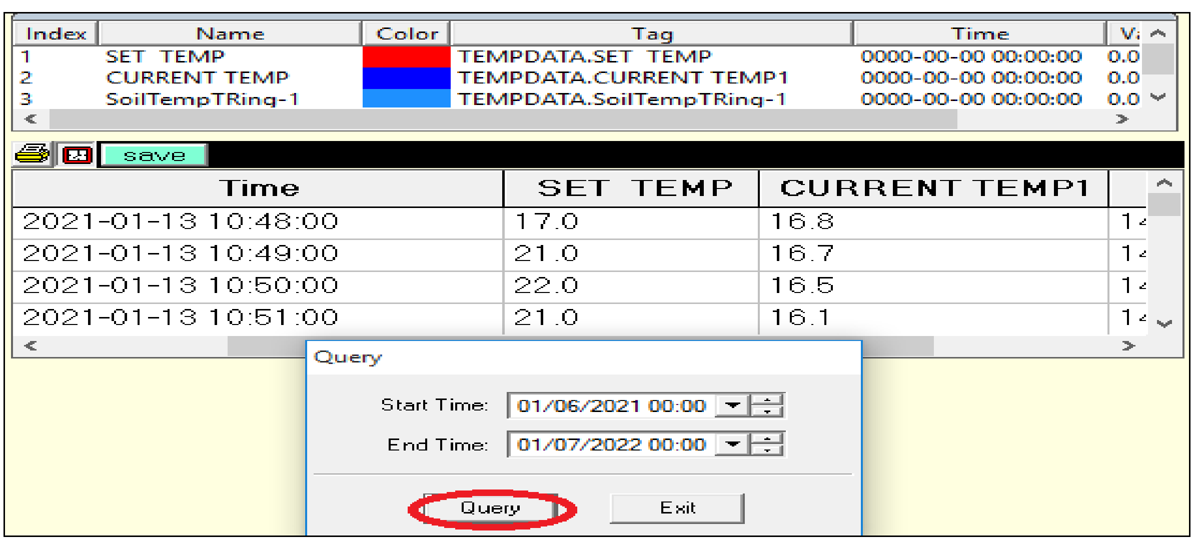


Fig. 27. Process for querying data

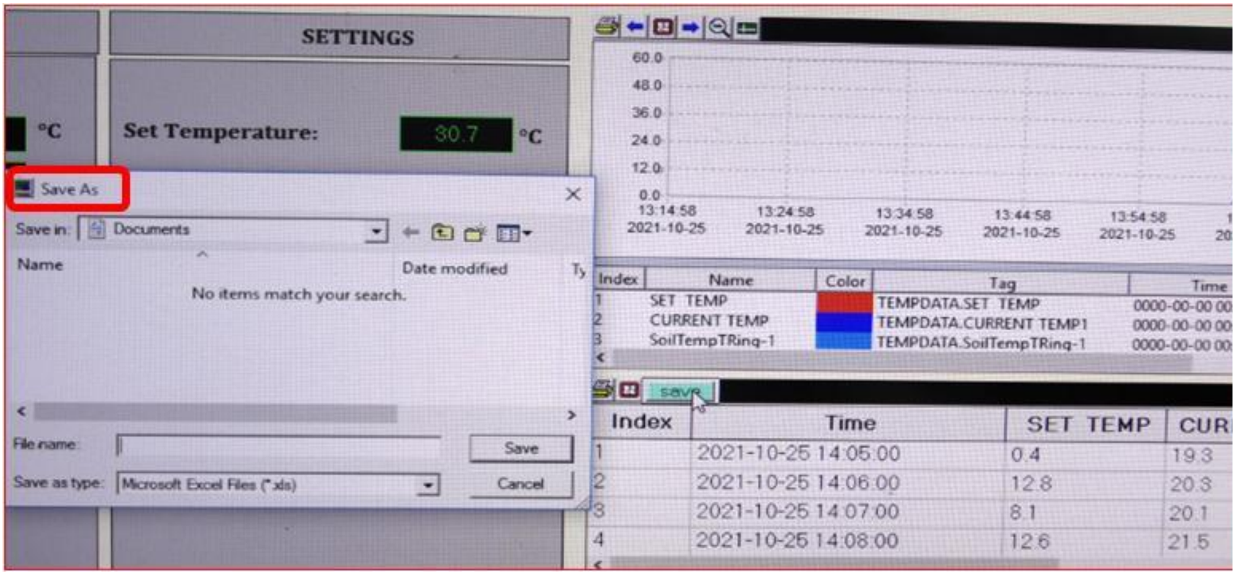
Step II): On clicking on the on the query button, a pop-up query option instantly appeared on screen for providing the data based on the desired 'start date' and 'end date' and accordingly, all the relevant data of different set of parameters like set temperature, current temperature, soil temperature-moisture sensor will be displayed on the SCADA software (as shown below in Figure 28).

Time	SET TEMP	CURRENT TEMP1	STRing-1	SMRing-1
2022-04-01 09:00:00	23.0	18.1	19.0	21.4
2022-04-01 09:01:00	22.0	18.6	19.0	21.3
2022-04-01 09:02:00	21.0	19.1	19.0	21.4
2022-04-01 09:03:00	22.0	18.8	19.0	21.4

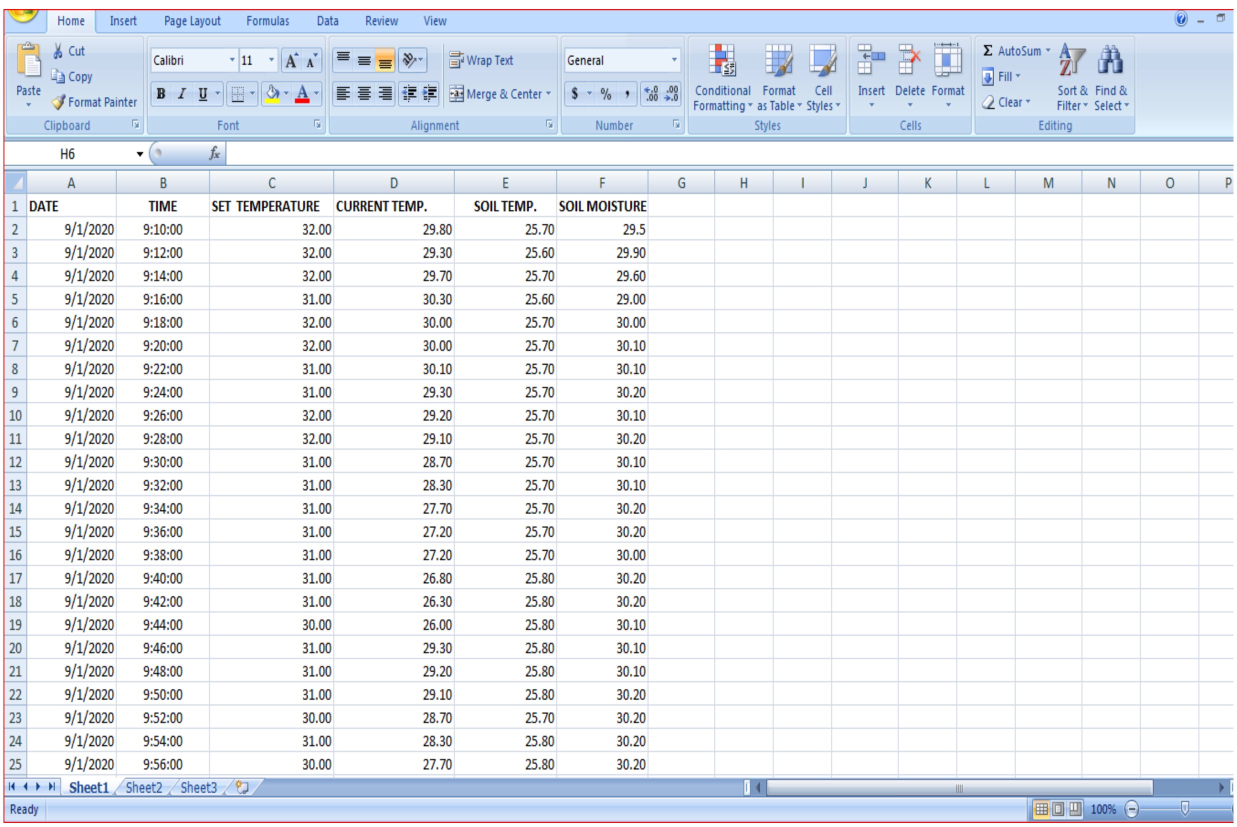
Fig. 28. The Different parameters in FATE rings monitored by SCADA

Step III): Then click on **'SAVE'** button for saving the data of different parameters. On clicking the 'SAVE' button, a **'SAVE AS**' pop-up will be displayed on the screen to save the recorded data in the file to be stored in the computer for research purposes and future reference (as shown in the below figure).

Time	SET TEMP	RH1	
2021-12-09 12:40:00	29.5	42.2	29.4
2021-12-09 12:45:00	29.5	42.2	29.4
2021-12-09 12:50:00	29.5	42.2	29.4
2021-12-09 12:55:00	29.5	42.2	29.4
2021-12-09 13:00:00	29.5	42.2	29.4
2021-12-09 13:05:00	29.5	42.2	29.4
2021-12-09 13:10:00	29.5	42.2	29.4



Step IV: Once the file is saved, we can go to the location of the file that is being saved in the computer for any modification. The below figure is the sample for the recorded data in the excel file (Figure 29).



DATE	TIME	SET TEMPERATURE	CURRENT TEMP.	SOIL TEMP.	SOIL MOISTURE
9/1/2020	9:10:00	32.00	29.80	25.70	29.5
9/1/2020	9:12:00	32.00	29.30	25.60	29.90
9/1/2020	9:14:00	32.00	29.70	25.70	29.60
9/1/2020	9:16:00	31.00	30.30	25.60	29.00
9/1/2020	9:18:00	32.00	30.00	25.70	30.00
9/1/2020	9:20:00	32.00	30.00	25.70	30.10
9/1/2020	9:22:00	31.00	30.10	25.70	30.10
9/1/2020	9:24:00	31.00	29.30	25.70	30.20
9/1/2020	9:26:00	32.00	29.20	25.70	30.10
9/1/2020	9:28:00	32.00	29.10	25.70	30.20
9/1/2020	9:30:00	31.00	28.70	25.70	30.10
9/1/2020	9:32:00	31.00	28.30	25.70	30.10
9/1/2020	9:34:00	31.00	27.70	25.70	30.20
9/1/2020	9:36:00	31.00	27.20	25.70	30.20
9/1/2020	9:38:00	31.00	27.20	25.70	30.00
9/1/2020	9:40:00	31.00	26.80	25.80	30.20
9/1/2020	9:42:00	31.00	26.30	25.80	30.20
9/1/2020	9:44:00	30.00	26.00	25.80	30.10
9/1/2020	9:46:00	31.00	29.30	25.80	30.10
9/1/2020	9:48:00	31.00	29.20	25.80	30.10
9/1/2020	9:50:00	31.00	29.10	25.80	30.20
9/1/2020	9:52:00	30.00	28.70	25.70	30.20
9/1/2020	9:54:00	31.00	28.30	25.80	30.20
9/1/2020	9:56:00	30.00	27.70	25.80	30.20

Fig. 29.The recorded data in the excel file

Chapter 6: FATE- Managing the liquid CO_2

The CO_2 supply system is consisting of CO_2 storage tank of **20 Kiloliters (20 Metric Ton)** liquid CO_2 storing capacity (Figure 30a and b) with all the necessary accessories to maintain the liquid, gas pressure, and with relevant safety devices. The storage tank is installed on a RCC basement in accordance to Indian standards. The license for storing of the Liquid CO_2 gas is obtained from the competent agencies like **Petroleum Explosives Safety Organization (PESO)** for CO_2 tank. SS 304 grade seamless tubing is done for CO_2 supply from the CO_2 tank to the FATE rings.

The FATE rings with elevated CO_2 gas conditions are provided with proper monitoring system and controls to maintain uniform CO_2 gas concentration.

- The CO_2 gas concentration supplied and maintained for elevated conditions in FATE is around 550ppm through SCADA.
- Solenoid valves are used for the spraying of the CO_2 gas and CO_2 gas analyzer together with the CO_2 gas filter measures or analyze the concentration of the CO_2 gas in FATE rings.
- Supply of CO_2 gas through pipelines (Figure 31) from storage tank to FATE rings is done safely by passing through safety pressure regulators and pressure gauges.

Fig. 30a.(Front view) Liquid CO_2 storage tank (20 metric ton capacity)

Fig. 30b.(Side-view) Liquid CO_2 storage tank (20 metric ton)

Fig. 31.Supply of CO_2 gas through Pipelines from tank to CTGC chambers and FATE Rings through safety pressure regulators and pressure gauges.

6.1. Safety Relief Valves (SRVs)

These are spring-loaded safety pressure releasing valves (Figure 32) use for control the limiting pressure of the CO_2 gas pressure stored in the closed storage vessel. The working of the SRVs is such that the pressure is relieved by permitting the pressurized fluid to flow from an auxiliary passage out of the system.

The safety valves are designed at a pre-determined set pressure i.e. 24 kg/cm^2 for protecting the pressure vessels from excess pressure. If this pressure exceeds the pre-determined set pressure (24 kg/cm^2), then blasting of the CO_2 gas through the valves will occur to reduce the pressure.

Fig. 32. Safety Relief Valves

6.2. Chiller system:

A chiller unit (Figure 33) is a cooling machine designed for removing heat from the process-fluid by using a refrigerant called Freon gas (R134A). The working principle of a Chiller is same as that of a vapor-compression i.e. it provides a continuous flow of coolant or refrigerant to the cold side of a process- water system at a desired low temperature.

The coolant is pumped and is circulated throughout in the process by extracting the heat from the hot CO_2 gas stored in a storage tank as it flows back to the return side of the process water system in a liquid form.

Fig. 33. Chiller system

Working Principle of Chiller:

The cyclic process of cooling the liquid CO_2 gas in the storage tank is based on the refrigeration cycle in order to reduce the pressure and temperature of the liquid CO_2 gas storage tank takes place in the following components (Figure 34)

1). Evaporator: Heat is absorbed from the CO_2 gas by the refrigerant thereby changing its state from liquid state to low-pressure vapour form.
2). Compressor: This low-pressure vapour then compresses the vapour to the high-pressure vapour.
3). Condenser: This high-pressure vapour which flows through coil are in this unit is cooled down by rejection of heat into the atmosphere and changes its state to high-pressure liquid. **Rejection of heat is done with the help of exhaust fans**.
4). Expansion valve: This high-pressure liquid is expanded (made to pass through a very small volume) hence reducing the pressure thereby changing its state to low-pressure vapour.

The above four components collectively work as a single unit in a cyclic process for reducing the pressure of the CO_2gasand maintains it at a safety limit i.e. 24 kgf/cm^2.

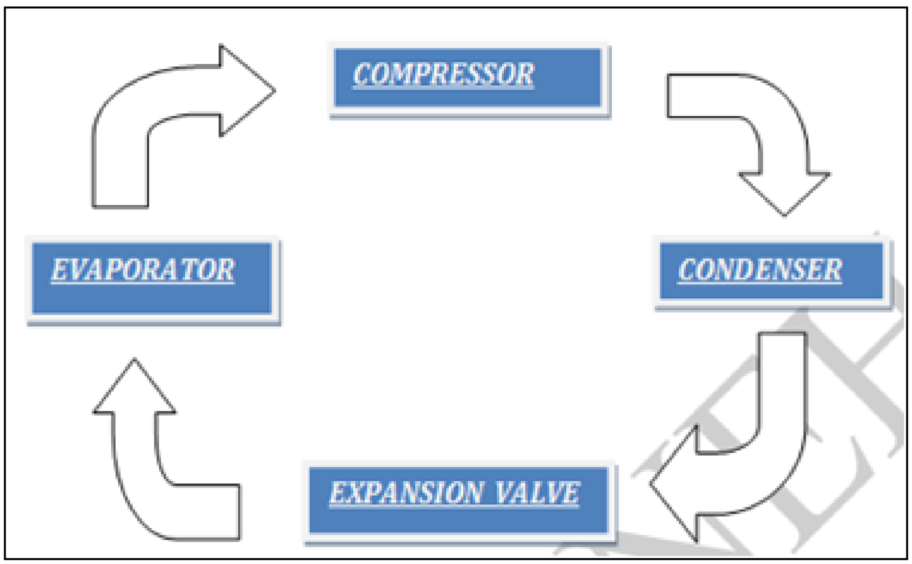


Fig. 34. The four basic components of Refrigeration cycle in Chiller

6.2.1. Operation of chiller:

i). As shown in the below figure (Figure 35), the pressure of the CO_2 gas in the storage tank almost reaches 20 kgf/cm^2.

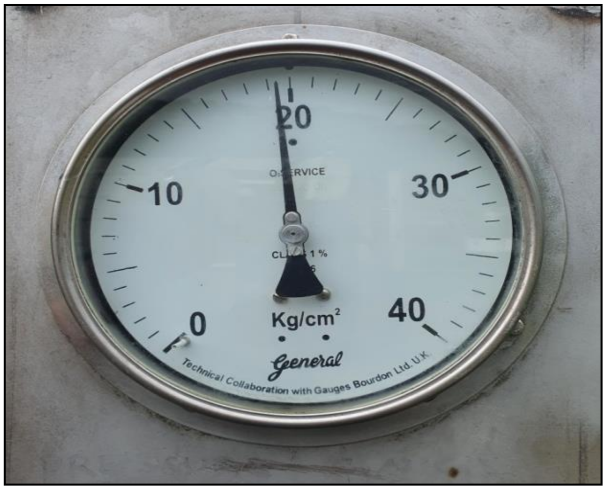


Fig. 35.Pressure meter on a storage tank

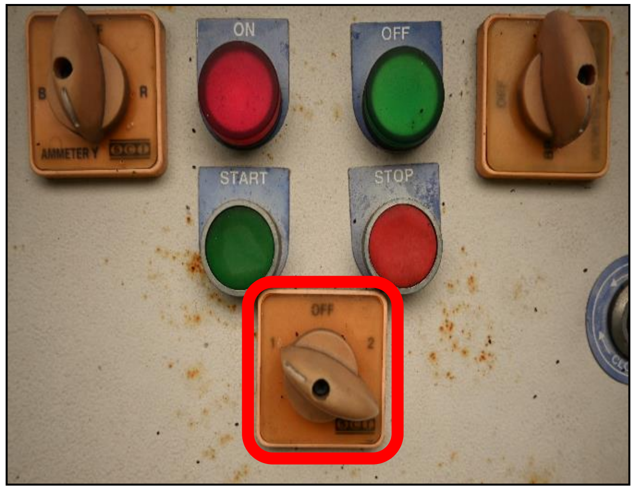


Fig. 36.The Chiller is set in AUTO-MODE condition(the switch is turned to the left for auto mode)

ii). The Chiller can operate in auto-mode and manual mode. But for convenience and safety reasons, it is recommended to set in auto-mode as shown in the Figure 36. For auto-mode, the switch marked in 1 has to be turned to the left while for manual mode; it has to be turned to the right (marked 2 on the switch panel).

iii). Now as the Chiller is set in AUTO-MODE, when the pressure the CO_2 gas in the storage tank reaches the pressure of 20 kgf/cm^2, it will automatically operates by itself to reduce the pressure of the Liquid CO_2 storage tank.

As the Chiller runs, we should notice that the formation of ice in the in the expansion valve (as shown in the below (Figure 37) occurs regularly indicating the following:

- The process of reducing the CO_2 gas pressure to a safety limit
- The hot CO_2 gas is undergoing phase change to liquid form

Fig. 37. Formation of ice (marked in red) in the Chiller machine

The Chiller automatically stops operating when the pressure of the CO_2 gas in the storage tank reduces down to a safety pressure i.e. below 18 kgf/cm^2.

The Chiller is set in AUTO-MODE condition so that when the pressure of the CO_2 gas in the storage tank reaches the setting pressure of 20kgf/cm^2, the machine automatically operates by itself in order to reduce the pressure to a safety limit.

6.2.2. Diesel Generator of 200kVA (160 kilowatts)

Since the cooling process is a time-consuming process i.e. it takes approximately 7-8 hours just for reducing the pressure of 2 units i.e. from 20 kgf/cm^2 to 18 kgf/cm^2. Therefore, in order to avoid the power interruption during the working operation of the FATE system and Chiller that may be due load shedding or any maintenance related-works, the DG set (Diesel Generator, Figure 38) is use as a power back-up for providing continuous power supply to the research facilities like FATE & Chiller.

Specifications of the DG set

Genset Prime Rating (kVA):	200kVA
Current (Ampere); Frequency (Hz); RPM	278 A; 50 Hz; 5000 RPM
Maximum Power (kilo-Watt)	160 kW
Maximum Fuel capacity in liters	400 liters
Fuel Consumption	
• @ 75% load (liter per hour);	33.3 liters
• @ 100% load (liter per hour)	40.8 liters

Fig. 38. The Diesel Generator use for power backup of FATE & Chiller

Operation of DG set: In the absence of electrical power supply from the grid, the DG set (Figure 39) can be used to power the research facilities like FATE System and Chiller.

Manual Mode:

1. Push the switch to 'ON' position.
2. Press the 'Start' button to start the DG Set.
3. Press the 'Stop' button to stop the DG Set.

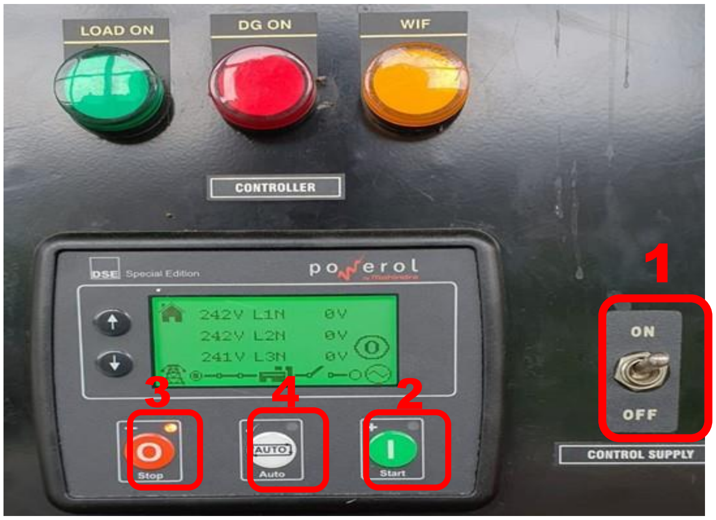


Fig. 39. The Control Panel of the DG Set

Auto-mode:

4. Press the 'Auto' button so it automatically starts the DG set in the absence of electrical power and automatically stops the DG set in the presence of electrical power. However, it is recommended that the DG set is always kept in an auto mode condition so that it automatically operates by itself in the absence of a concerned person.

References

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