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Prediction and Appraisal of solar radiations and its Intensity in South East Geopolitical Region, Nigeria

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Original Research Article

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Abstract: This research work is shows the variability of solar parameters. The parameters that are solar radiation, sun intensity and temperature were optimized and predicted in other to investigate its influence in Permanent site of Federal Polytechnic, Oko, Anambra State, South Eastern part of Nigeria. The research was conducted for the period of five days, 6:00am to 6:00pm daily on 6th to 10th December, 2017. Measuring the intensity of solar radiation is one of the directions used at investigation of solar power and necessary for the implementation of photovoltaic systems in a particular geographical 'area. Instrument used for measuring the solar radiation is solarimeter which is based on the thermal or photovoltaic principles. The device harness two main components for measuring solar radiation, namely- direct radiation and diffuse radiation, with sensors based on the photovoltaic principles. The research tends to optimize and to develop the intended sun intensity and solar radiation principles and properties of the environs. From the optimization results, the maximum sun intensity of the geographical area is 957.620 w/m^2 while the minimum sun intensity of the area is 2 w/m^2. However, the maximum temperature of the geographical area is 39.4˚C while the minimum temperature of the geographical area is 18.8˚C. The average sun intensity of the case study is 356.644w/m^2**.** The optimization technic employed will ensure the efficiency of solar radiation, sun intensity and temperature variability of the geographical area in study as a key to climatic issues and solar systems manufacturing.

Keywords: Optimization, Prediction, Factorial Design, Sun intensity, Solar Systems, Solar radiations and Photovoltaic.

INTRODUCTION

Solar Constant

The Sun is considered to produces a constant amount of energy. The amount of energy produced by the sun is the solar radiation or the short wave energy. The solar radiation intensity falling on a surface is called irradiance or insolation and is measured in W/m^2 or kW/m^2 [1]. The solar constant can be used to calculate the irradiance incident on a surface perpendicular to the Sun's rays outside and the Earth's atmosphere on any day of the year. At the surface of the Sun the intensity of the solar radiation is about 6.33×10^7 W/m^2 (note that this is a power, in watts, per unit area in meters). The Sun's rays spread out into space the radiation becomes less intense and by the time the rays reach the edge of the Earth's atmosphere they are considered to be parallel [2].

The solar constant (I_{SC}) is the average radiation intensity falling on an imaginary surface, perpendicular to the Sun's rays and at the edge of the Earth's atmosphere. The word 'constant' is a little misleading since, because of the Earth's elliptical orbit the intensity of the solar radiation falling on the Earth changes by about 7% between January 1st, when the Earth is nearest the Sun, and July 3rd, when the Earth is furthest from the Sun. A yearly average value is thus taken and the solar constant on the earth equals 1367 W/m^2. Even this value is inaccurate since the output of the sun changes by about ±0.25% due to Sun spot cycles.

Figure-1 shows the variation in I_0 over the course of a year. Most solar power calculations use I_0 as a starting point because, for any given day of the year it is the maximum possible energy obtainable from the Sun at the edge of the Earth's atmosphere. The dashed line shows the value of the solar constant (Isc)

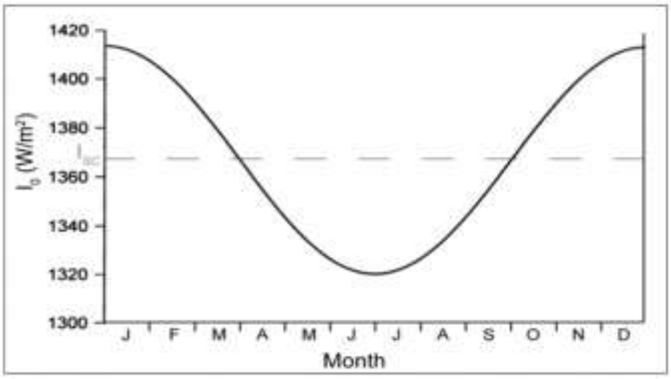

Fig-1: The variation in Io over the course of a year.

Irradiation

Just to be confusing the intensity of solar radiation is called irradiance and is measures in the units of power per unit area (W/m^2 or kW/m^2) however, the total amount of solar radiation energy is called irradiation and is measures in the units of energy per unit area (J/m^2). Irradiation is given the symbol H, so that:

- H_0 is the total daily amount of extraterrestrial radiation on a plane perpendicular to the Sun's rays;
- H_{0h} is the total daily amount of extraterrestrial radiation on a plane horizontal to the Earth's surface.

Note that these planes are considered to rotate with the Earth so that H_0 and H_{0h} are daily values, and the planes are shaded at night. Figure-2 & 3 shows how the values of H_0 and H_{0h} varies throughout the year in the northern hemisphere. Note that for any given day the value of H_0 changes from latitude to latitude despite the value of I0 being constant for all latitudes. This occurs because the length of the day's changes and the effects is most obvious inside the Arctic Circle where much of the year is either 24 hours of darkness or 24 hours of daylight [3].

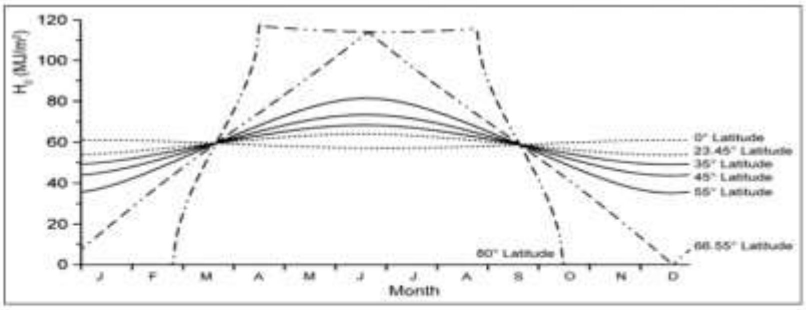

Fig-2: The total daily amount of extraterrestrial irradiation on a plane perpendicular to the Sun's rays (H0) for different latitudes

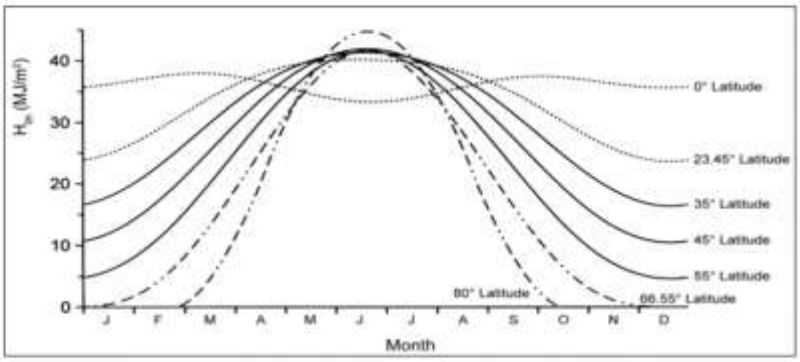

Fig-3: The total daily amount of extraterrestrial irradiation on a plane horizontal to the Earth's surface (H0h) for different latitudes.

The Solar Spectrum

The Sun’s radiation is a good approximation of black body radiation (a continuous distribution of wavelengths with no wavelengths missing) with wavelengths in the range of about 0.2 µm to 2.6 µm (figure 2.5). The solar spectrum consists of ultra-violate rays in the range of 200 to 400 nm, visible light in the range 390 nm (violet) to 740 nm (red) and the infra-red in the range 700 nm to 1mm [4].

Solar energy

Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis [5, 6].

It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air [7].

The large magnitude of solar energy available makes it a highly appealing source of electricity. The United Nations Development Programme in its 2000 World Energy Assessment found that the annual potential of solar energy was 1,575–49,837 exajoules (EJ). This is several times larger than the total world energy consumption, which was 559.8 EJ in 2012 [8, 9].

In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries’ energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating global warming, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared" [5].

Sunlight is a portion of the electromagnetic radiation given off by the Sun, in particular infrared, visible, and ultraviolet light. On Earth, sunlight is filtered through Earth's atmosphere, and is obvious as daylight when the Sun is above the horizon. When the direct solar radiation is not blocked by clouds, it is experienced as sunshine, a combination of bright light and radiant heat. When it is blocked by clouds or reflects off other objects, it is experienced as diffused light. The World Meteorological Organization uses the term "sunshine duration" to mean the cumulative time during which an area receives direct irradiance from the Sun of at least 120 watts per square meter [10]. Other sources indicate an "Average over the entire earth" of "164 Watts per square meter over a 24 hour day"[11].

The ultraviolet radiation in sunlight has both positive and negative health effects, as it is both a principal source of vitamin D_3 and a mutagen.

Sunlight takes about 8.3 minutes to reach Earth from the surface of the Sun. A photon starting at the center of the Sun and changing direction every time it encounters a charged particle would take between 10,000 and 170,000 years to get to the surface [12]

Sunlight is a key factor in photosynthesis, the process used by plants and other autotrophic organisms to convert light energy, normally from the Sun, into chemical energy that can be used to fuel the organisms' activities.

Researchers may record sunlight using a sunshine recorder, pyranometer, or pyrheliometer. To calculate the amount of sunlight reaching the ground, both Earth's elliptical orbit and the attenuation by Earth's atmosphere have to be taken into account. The extraterrestrial solar illuminance (E_{ext}), corrected for the elliptical orbit by using the day number of the year (dn), is given to a good approximation [13].

If the extraterrestrial solar radiation is 1367 watts per square meter (the value when the Earth–Sun distance is 1 astronomical unit), then the direct sunlight at Earth's surface when the Sun is at the zenith is about 1050 W/m^2, but the total amount (direct and indirect from the atmosphere) hitting the ground is around 1120 W/m^2 [1]

RESEARCH METHODS

The research method used is the qualitative method of experimental analysis using optimization tools. The experimental method applied is the factorial design method, to analyze and to optimize the experimental data of the case study. The results will portray the minimum and maximum optimal solar radiation in the experimental geographical area.

RESULTS AND ANALYSIS OF THE EXPERIMENT

Table-1: Solar Intensity for Five Days

S/N	Time	Intensity of the sun day 1 (W/M2)	Intensity of the sun day 2 (W/M2)	Intensity of the sun day 3 (W/M2)	Intensity of the sun day 4 (W/M2)	Intensity of the sun day 5 (W/M2
1	6:00	2.1	3.1	1.9	1.2	1.7
2	6:30	6.4	4.3	9.3	7.7	4
3	7:00	25.1	37.7	21.4	26.5	27.8
4	7:30	75.6	85.4	79.6	43.2	57.8
5	8:00	142.5	106.5	147.5	88.2	207.9
6	8:30	224.3	334.6	264.2	181.6	239.4
7	9:00	438.3	380.5	371.2	3 46. 2	351.6
8	9:30	436.5	339.4	475	316.7	410.6
9	10:00	226.1	271.5	612.1	195.2	602.6
10	10:30	237.5	636.1	255.2	193.2	718.9
11	11:00	741.2	476.4	394.3	856.1	819.3
12	11:30	198.6	959.6	459.7	861.3	908
13	12:00	286	898.1	616	992	986
14	l2:30	858.4	491.6	917.6	944.6	1013.3
15	1:00	856.1	318.3	960.9	843.9	998.5
16	1:30	174.2	963.5	339	717.2	934.2
17	2:00	265.4	814.3	818.2	751.9	876.8
18	2:30	264	230.7	473.1	371.8	789.6
19	3:00	374.7	554.9	572.5	374.8	686.2
20	3:30	207.4	413	215.6	318.3	547.7
21	4:00	211.8	180.4	154.1	249.7	449.3
22	4:30	153.6	111.8	134	173.1	130.2
23	5:00	86.5	127.1	104	149	160.7
24	5:30	47.1	43.9	57.7	80.1	52.2
25	6:00	13.3	8.6	18.7	30.9	21.2

Estimated Regression Coefficients for Yields (Y)
Term Coef SE Coef T P
Constant 479.810 0.000000 * *
Intensity of the sun day 1 (W/M 85.6300.000000 * *
Intensity of the sun day 2 (96.040 0.000000 * *
Intensity of the sun day 3 (W 95.900 0.000000 * *
Intensity of the sun day 4 (W/M 99.080 0.000000 * *
Intensity of the sun day 5 (W/M101.160 0.000000 * *
Intensity of the sun day 1 (W/M* 0.000 0.000000 * *
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Intensity of the sun day 3 (W* 0.000 0.000000 * *
Intensity of the sun day 3 (W
Intensity of the sun day 4 (W/M* -0.000 0.000000 * *
Intensity of the sun day 4 (W/M
Intensity of the sun day 5 (W/M* -0.000 0.000000 * *
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Intensity of the sun day 1 (W/M* 0.000 0.000000 * *
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Intensity of the sun day 4 (W/M
Intensity of the sun day 1 (W/M* -0.000 0.000000 * *
Intensity of the sun day 5 (W/M
Intensity of the sun day 2 (* -0.000 0.000000 * *
Intensity of the sun day 3 (W
Intensity of the sun day 2 (* -0.000 0.000000 * *
Intensity of the sun day 4 (W/M
Intensity of the sun day 2 (* 0.000 0.000000 * *
Intensity of the sun day 5 (W/M
Intensity of the sun day 3 (W* 0.000 0.000000 * *
Intensity of the sun day 4 (W/M
Intensity of the sun day 3 (W* 0.000 0.000000 * *
Intensity of the sun day 5 (W/M
Intensity of the sun day 4 (W/M* 0.000 0.000000 * *
Intensity of the sun day 5 (W/M

S = 0 PRESS = * R-Sq = 100.00% R-Sq(pred) = *% R-Sq(adj) = 100.00%

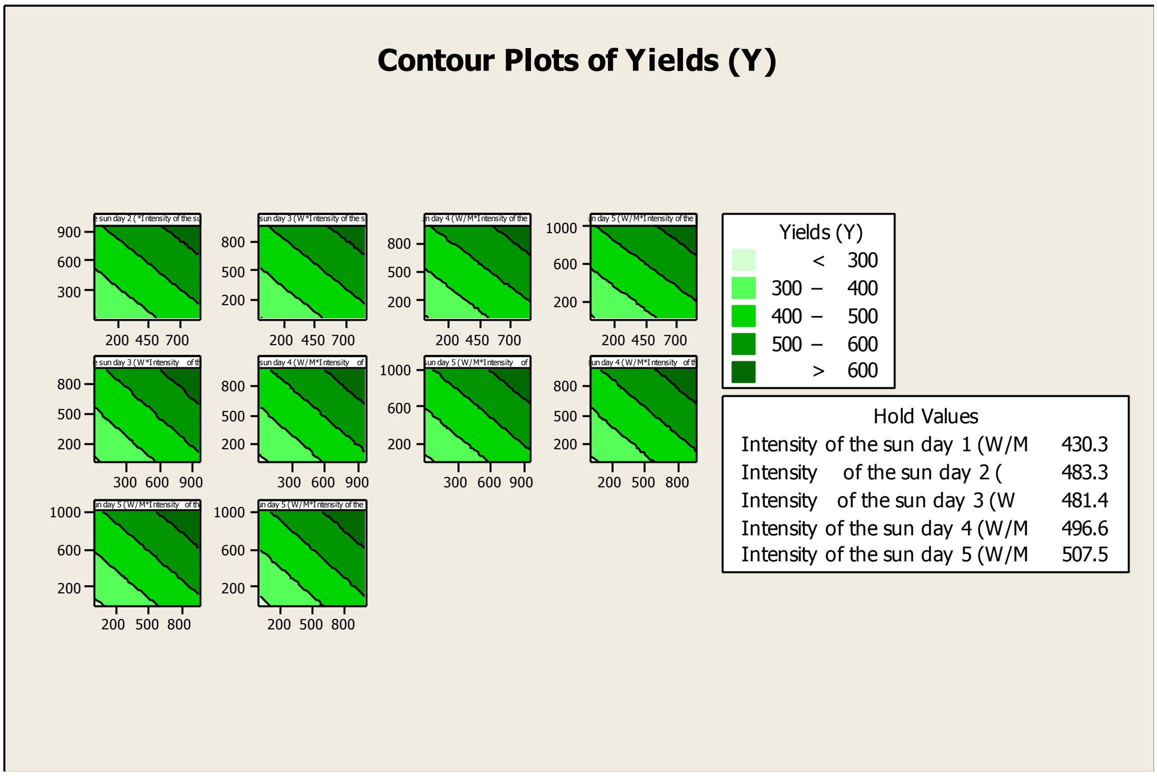

Fig-4: Contour Plots of Sun Intensity over the Experimental Periods

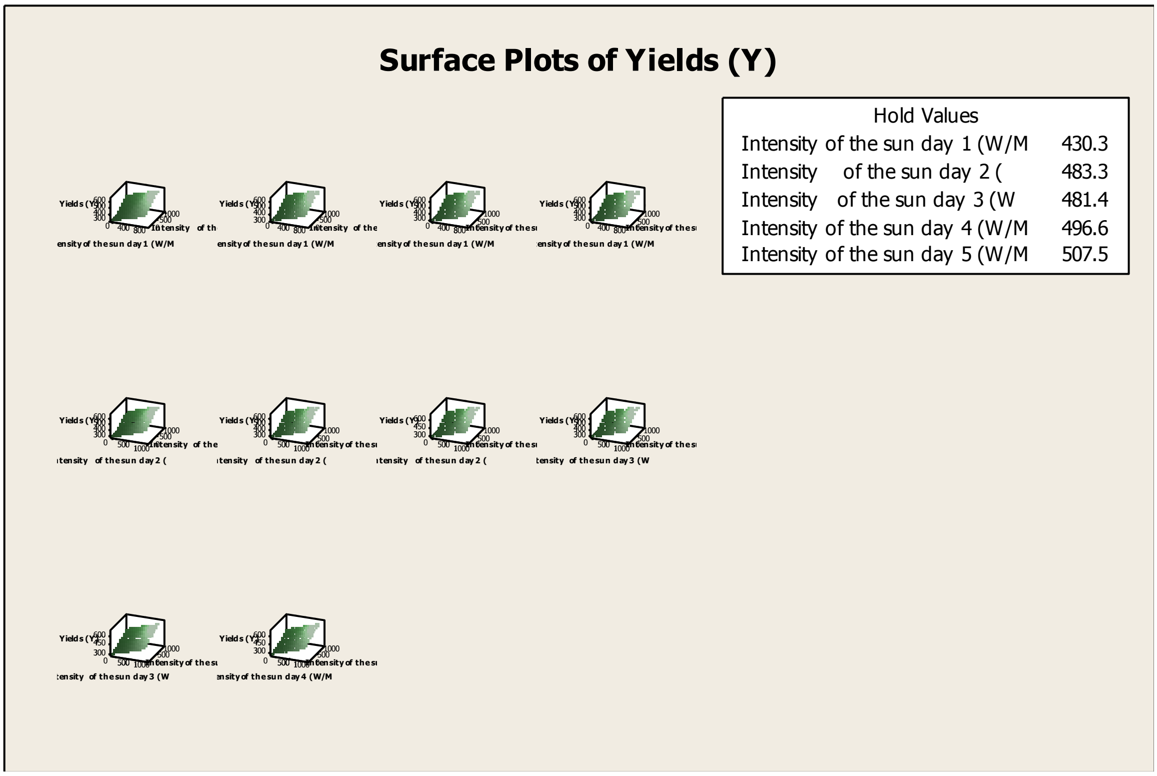

Fig-5: Surface Plots of Sun Intensity over the Experimental Periods

Response Optimization

Parameters

	Goal	Lower	Target	Upper	Weight	Import
Yields (Y)	Minimum	450	450	1000	1	1

Local Solution
Intensity of = 453.562
Intensity = 558.662
Intensity = 556.062
Intensity of = 587.162
Intensity of = 608.462

Predicted Responses
Yields (Y) = 552.782 , desirability = 0.813123

Composite Desirability = 0.813123

Global Solution
Intensity of = 2.1
Intensity = 3.1
Intensity = 1.9
Intensity of = 1.2
Intensity of = 1.7

Predicted Responses
Yields (Y) = 2, desirability = 1.000000
Composite Desirability = 1.000000

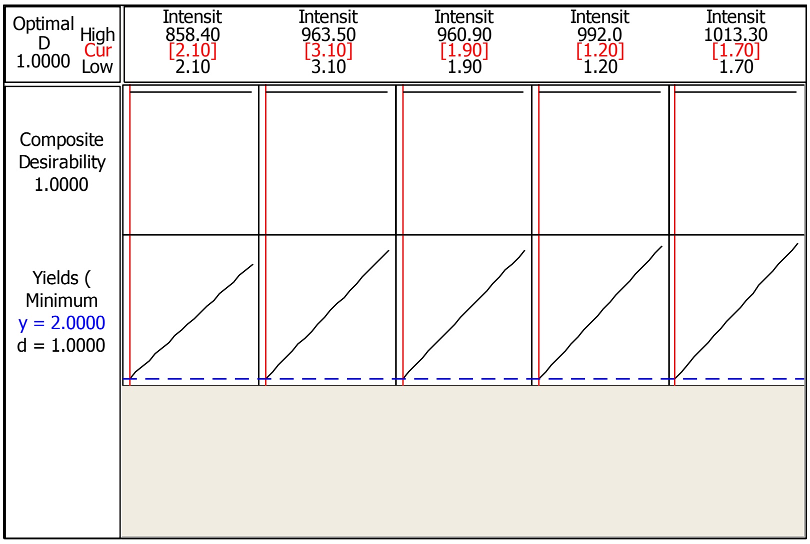

Fig-6: Minimum Optimization Plot for Sun Intensity

Response Optimization

Global Solution
Intensity of = 858.4
Intensity = 963.5
Intensity = 960.9
Intensity of = 992
Intensity of = 1013.3

Predicted Responses
Yields (Y) = 957.62, desirability = 1.000000

Composite Desirability = 1.000000

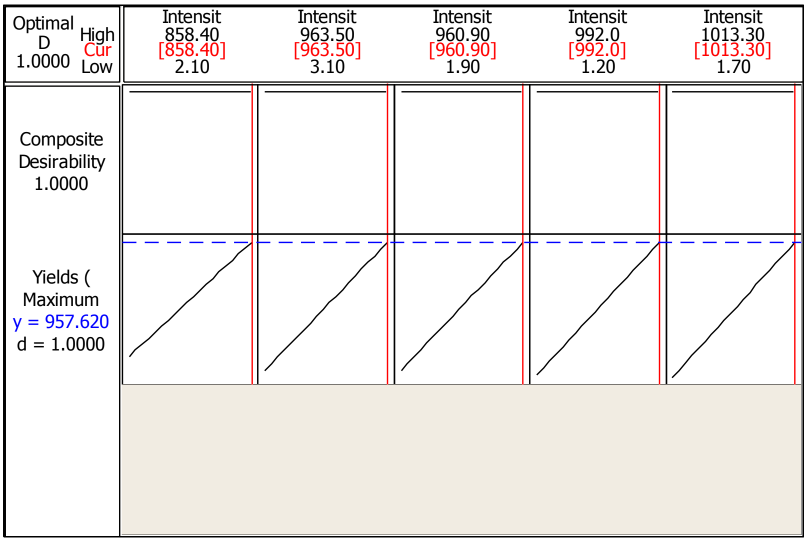

Fig-7: Maximum Optimization Plot for Sun Intensity

Table-2: The values of temperature for the Experimental Periods

S/N	Time	Temperature Day 1 ("C)	Temperature Day 2 ("C)	Temperature Day 3 ("C)	Temperature Day 4 ("C)	Temperature Day 5 ("C)
1	6:00	19.4	21.1	17.9	17.5	18.1
2	6:30	20.2	21.6	19.8	18.4	19.3
3	7:00	21.5	24.3	20.2	21	20.5
4	7:30	22.3	26.8	20.7	22.3	21.4
5	8:00	22.8	23.2	23.1	23.5	23.1
6	8:30	23.2	23.8	24.3	24.6	22.6
7	9:00	23.7	25.3	24.9	25.3	24.2
8	9:30	24.6	27.3	25.1	26.3	23.9
9	10:00	26.9	28.5	27.8	26.1	27.3
10	10:30	27.4	29.1	27.1	27.5	30.4
11	11:00	27.6	31.4	30.1	31.4	32.6
12	11:30	28.2	32.1	33.1	31.2	34.6
13	12:00	29.7	34.5	34.5	34.5	37.9
14	12:30	34.2	34.7	38.7	36.7	40.1
15	1:00	38.6	39	36.9	35.2	40.6
16	1:30	40.8	37.7	37.5	37.3	38.7
17	2:00	39.5	35.2	34.2	28.2	41.2
18	2:30	37.4	37.1	36.4	27.8	37.5
19	3:00	35.2	35.3	34.3	25.6	33.7
20	3:30	33.9	34.5	32.5	24.3	26.4
21	4:00	34	31.4	30.9	23.9	22.2
22	4:30	32.7	29.6	28.1	22.6	23.9
23	5:00	31.5	29.7	25.6	22.3	20.1
24	5:30	29.6	26.8	22.2	19.6	19.7
25	6:00	23.4	23.9	20.4	20.9	18.8

Factorial design Analysis of Temperature

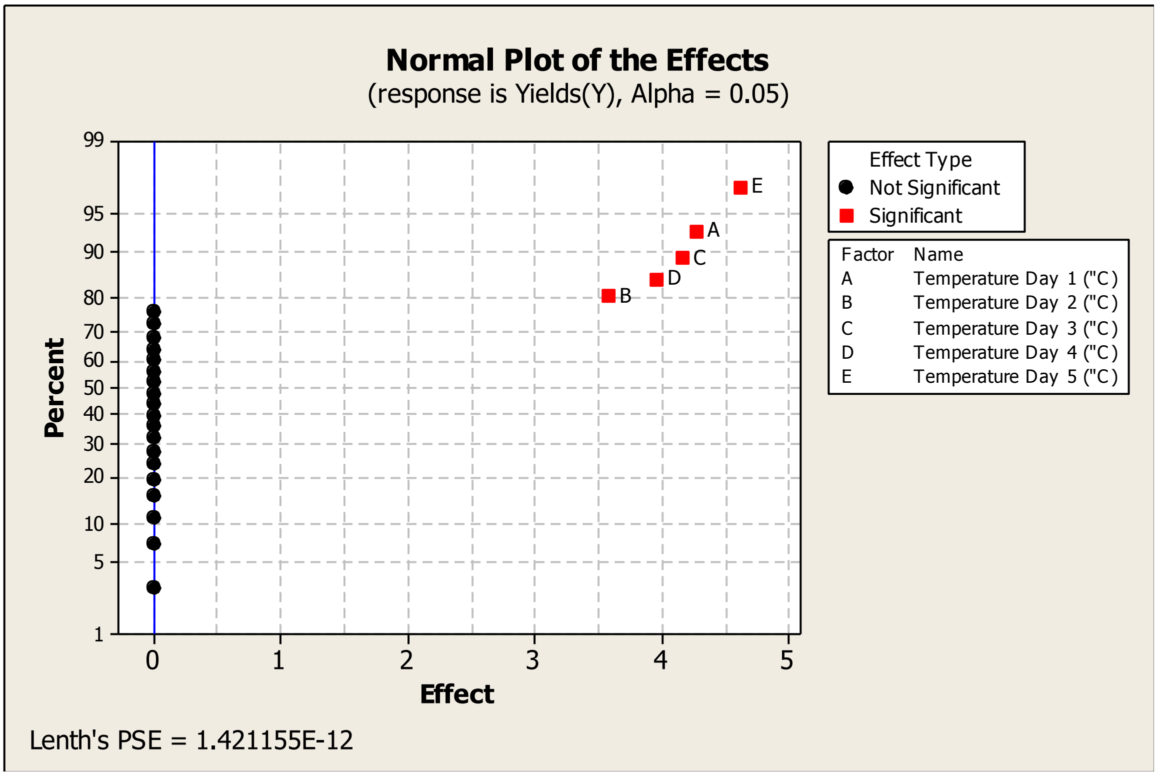

Fig-8: Effects Plot for Temperature

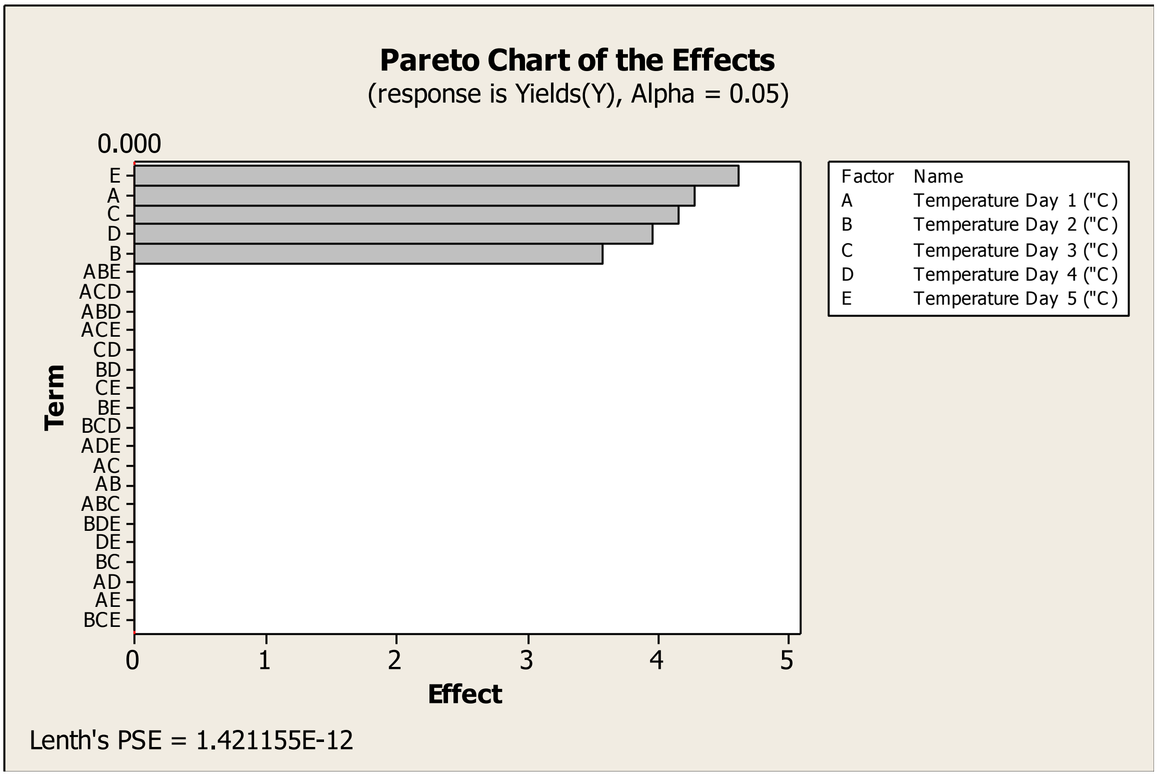

Fig-9: Effects Pareto Plot for Temperature

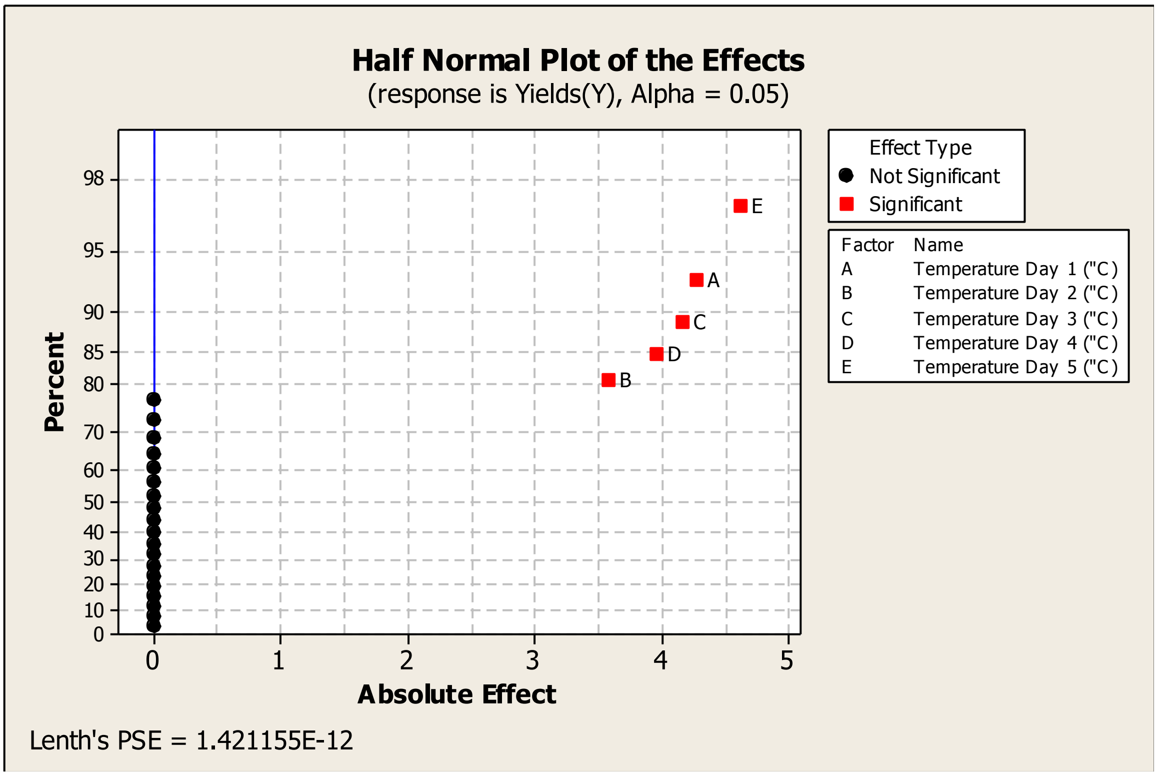

Fig-10: Half Normal Effects Plot for Temperature

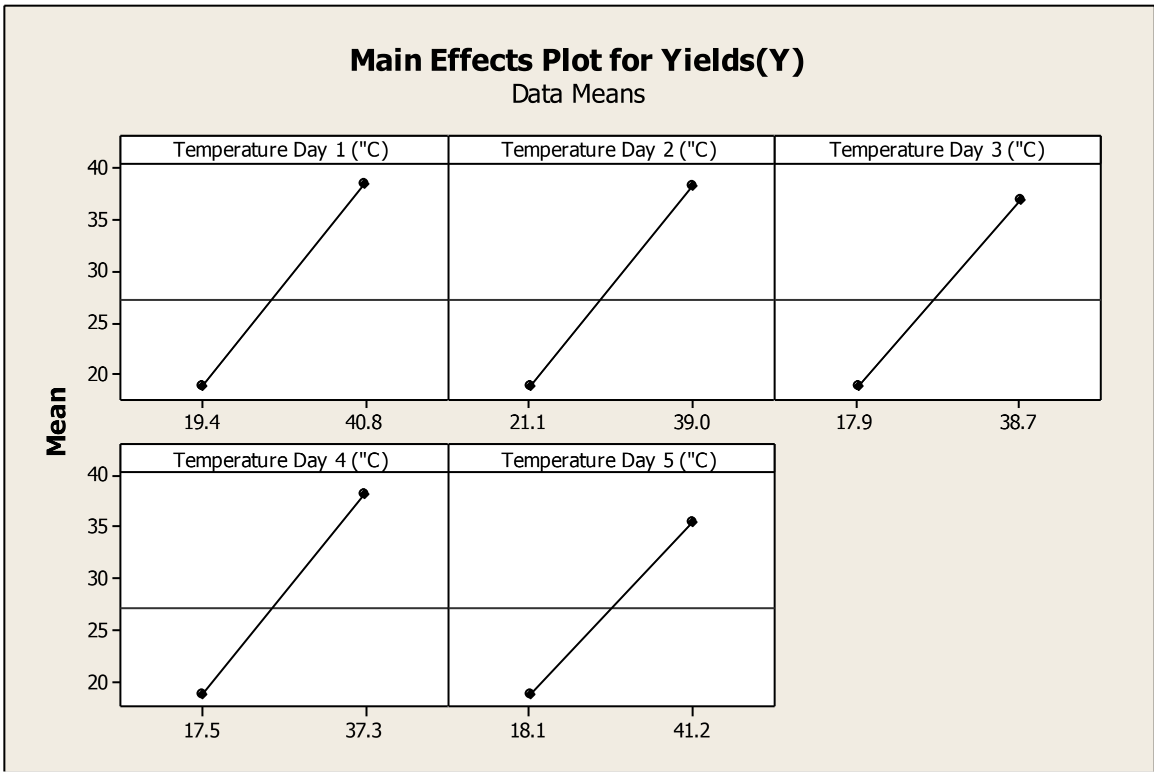

Fig-11: Main Effects Plot for Temperature Yields(Y)

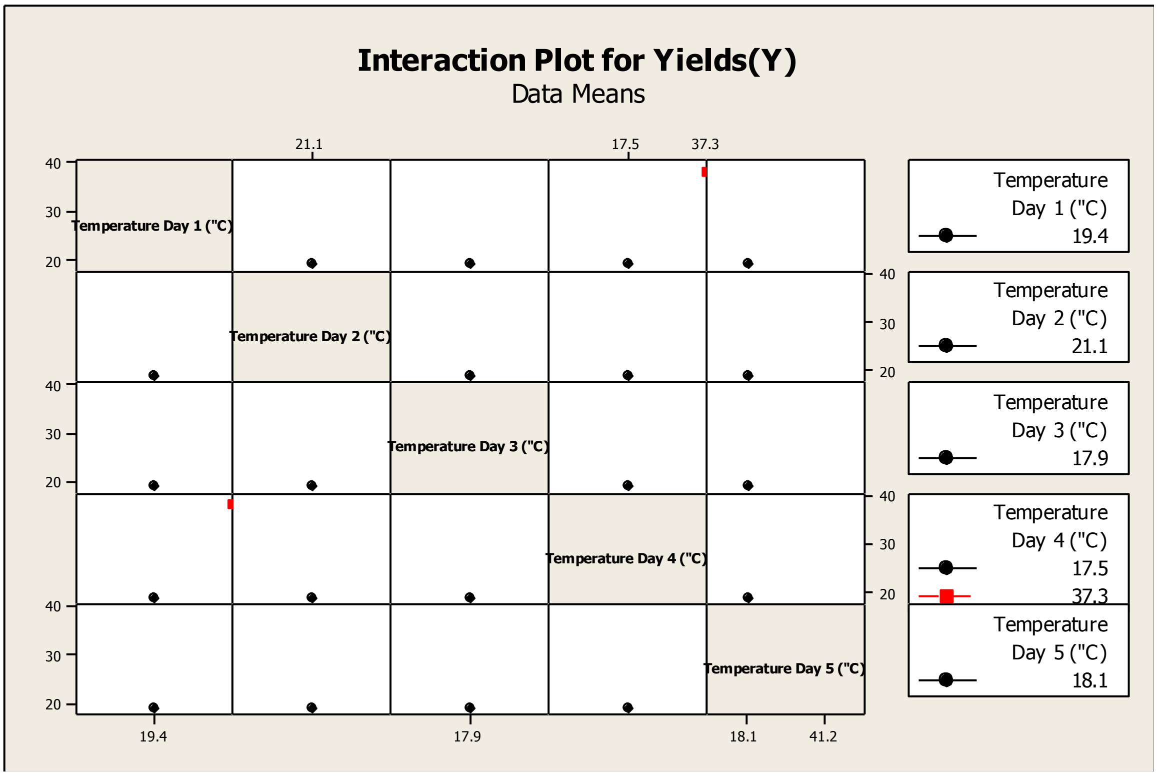

Fig-12: Interaction Plot for Temperature Yields(Y)

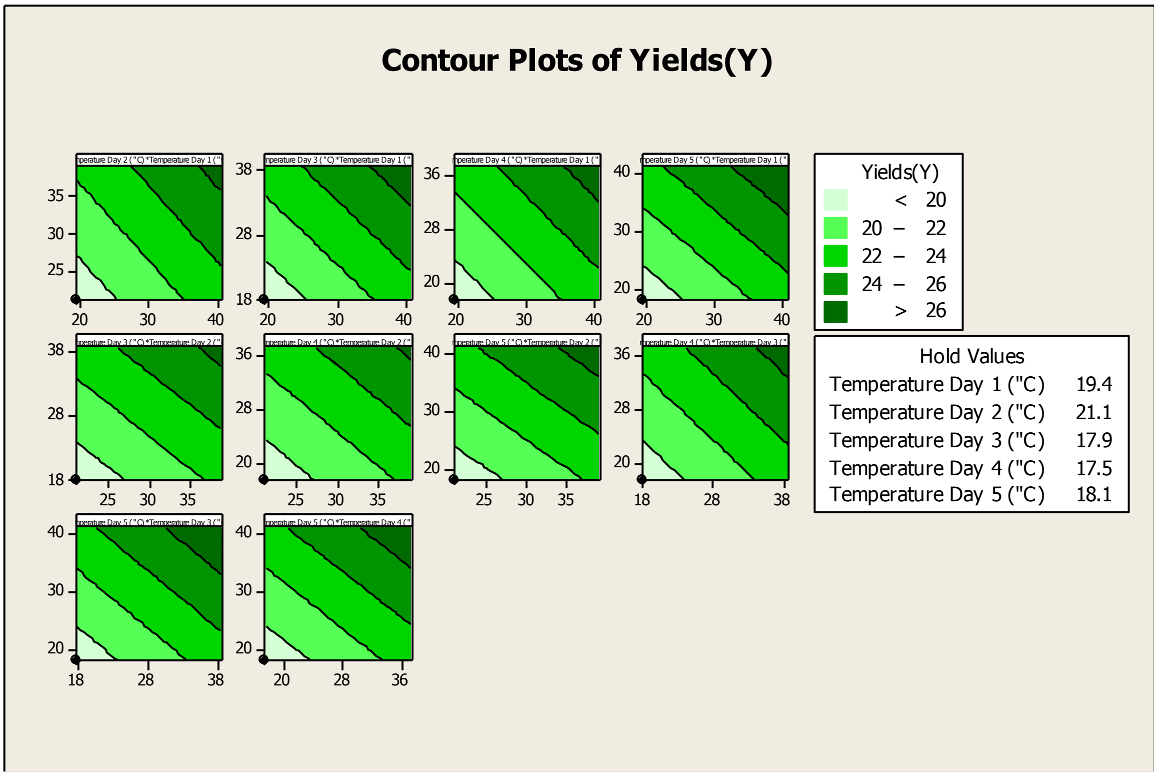

Fig-13: Contour Plots of for Temperature Yields(Y)

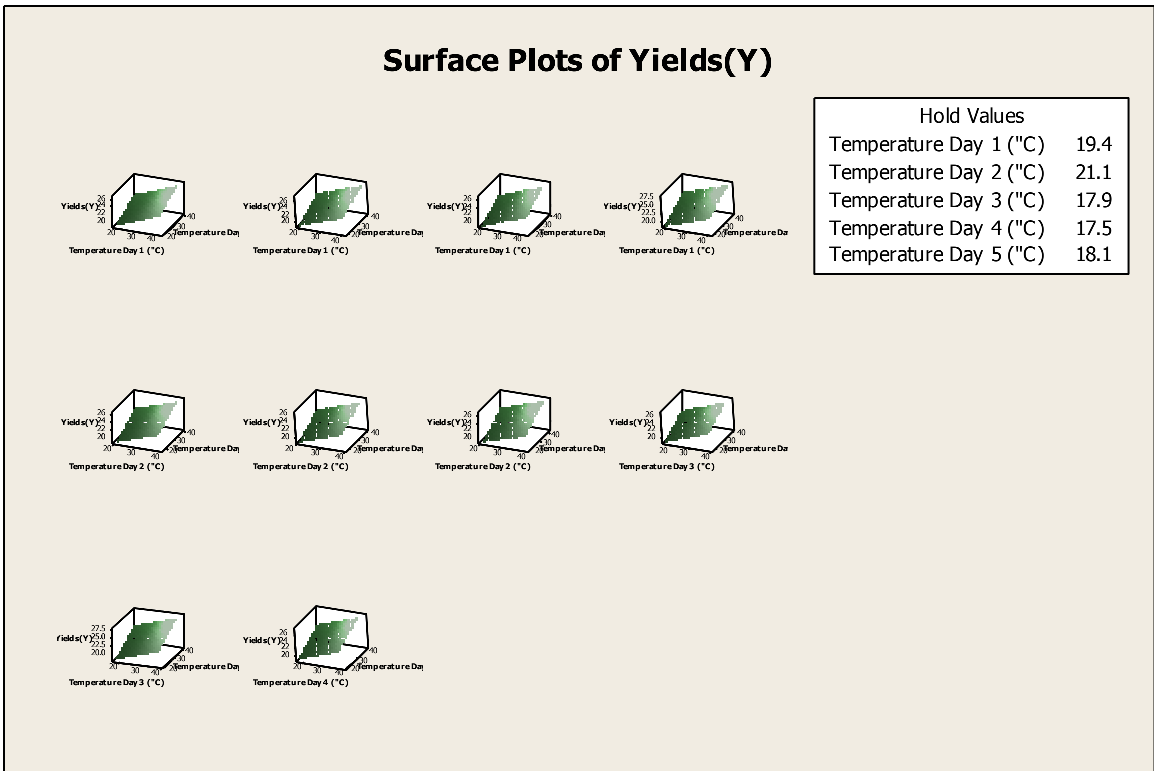

Fig-14: Surface Plots of for Temperature Yields(Y)

Response Optimization

Parameters

	Goal	Lower	Target	Upper	Weight	Import
Yields(Y)	Minimum	26	26	45	1	1

Local Solution
Temperature = 40.4526
Temperature = 38.6526
Temperature = 38.3526
Temperature = 36.9526
Temperature = 40.8526

Predicted Responses

Yields(Y) = 39.0526, desirability = 0.313023
Composite Desirability = 0.313023

Global Solution
Temperature = 19.4
Temperature = 21.1
Temperature = 17.9
Temperature = 17.5
Temperature = 18.1

Predicted Responses
Yields(Y) = 18.8, desirability = 1.000000

Composite Desirability = 1.000000

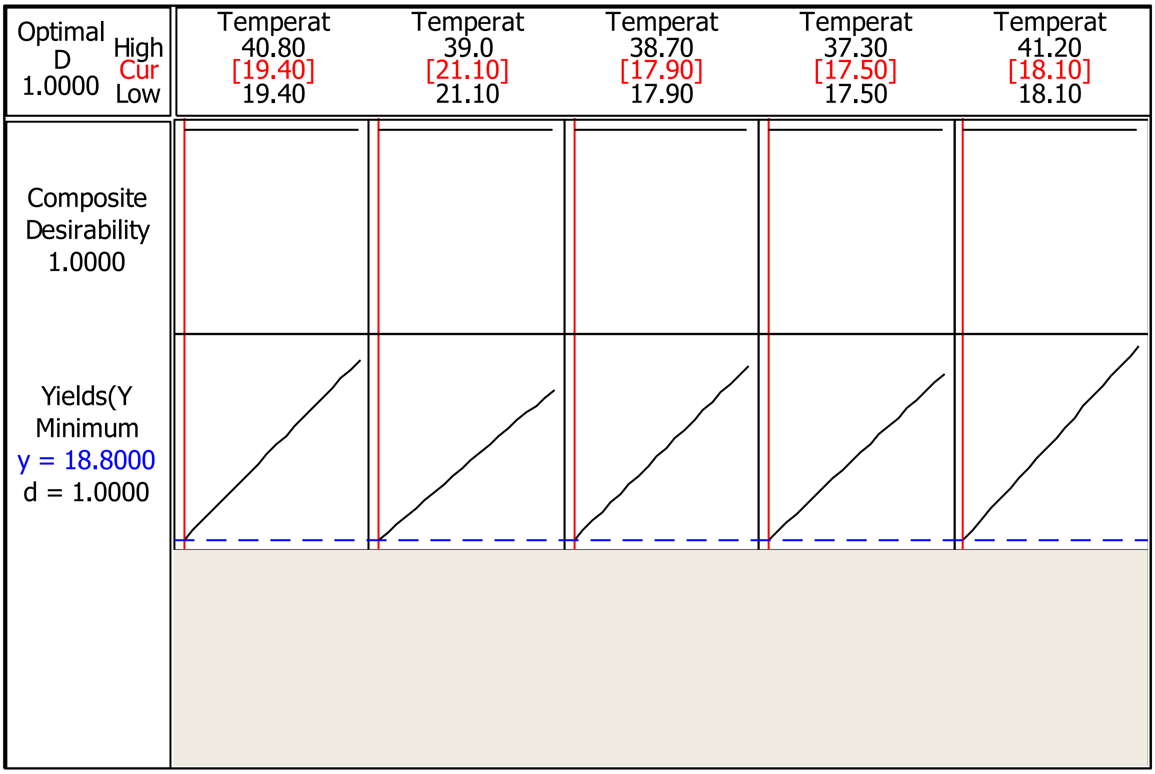

Fig-15: Optimization Plot for Temperature

Response Optimization

Parameters

	Goal	Lower	Target	Upper	Weight	Import
Yields(Y)	Maximum	16	26	26	1	1

Local Solution
Temperature = 21.4941
Temperature = 23.1941
Temperature = 19.9941
Temperature = 19.5941
Temperature = 20.1941

Predicted Responses
Yields(Y) = 20.8941, desirability = 0.489413
Composite Desirability = 0.489413

Global Solution
Temperature = 40.8
Temperature = 39
Temperature = 38.7
Temperature = 37.3
Temperature = 41.2

Predicted Responses
Yields(Y) = 39.4, desirability = 1.000000

Composite Desirability = 1.000000

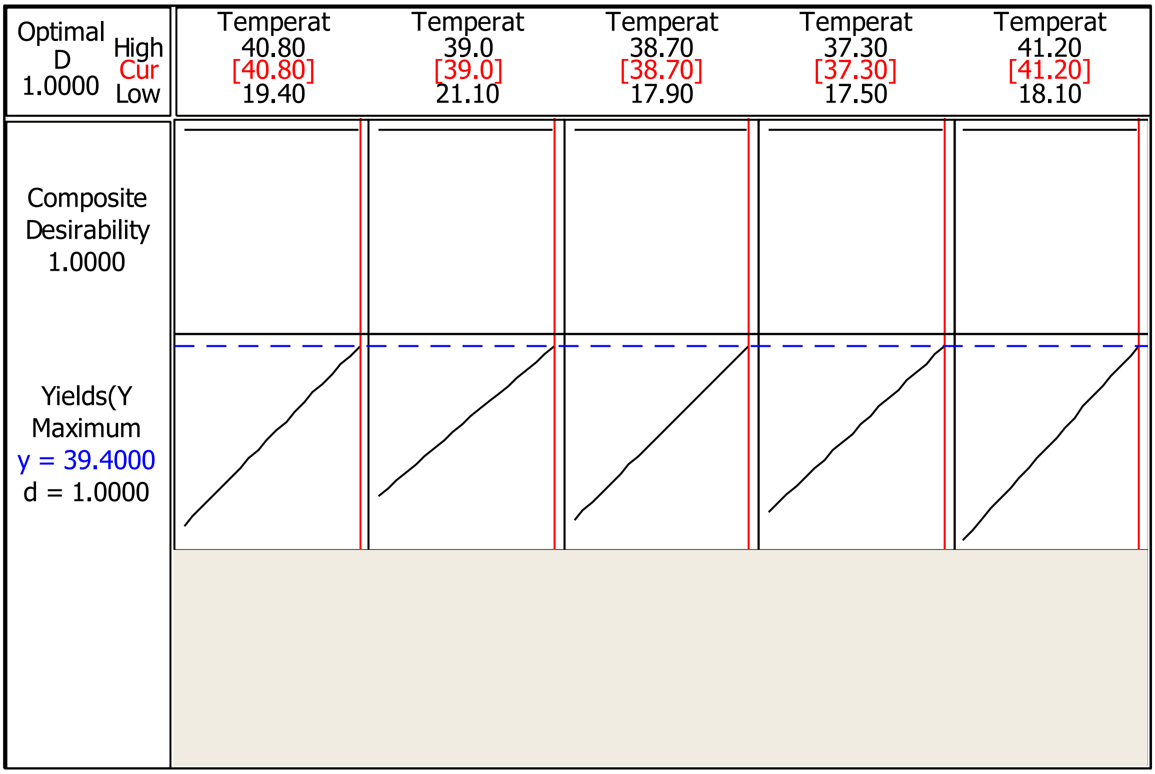

Fig-16: Optimization Plot for Temperature

DISCUSSION

This research was carried out in details to ensure that the solar power meter (solarimeter) was placed vertically with the sensor pointing to the direction of the sun and the temperature where noted down. In this research, the peak value of solar intensity was recorded on the 10th of February, 2017 which was the 5th day of the research work having a value of 1013.3w/m^2 and the same date has the peak temperature on the experiment to the 41.2˚C. From the analysis, it was observed that the Sun radiation is highest from around 12 noon to 2 pm of the day time and lowest around 6AM to 7AM in the morning hours and around 6 PM in the evenings. The high intensity is as a result of high atmospheric temperature in the area. The average solar intensity of extension site in Federal Polytechnic Oko, is 356.644w/m^2. The research reveals the optimal sun intensity and solar radiation principles and properties of the environs. From the optimization results, the maximum sun intensity of the geographical area is 957.620 w/m^2 while the minimum sun intensity of the area is 2 w/m^2. However, the maximum temperature of the geographical area is 39.4˚C while the minimum temperature of the geographical area is 18.8˚C. The optimization technic employed will ensure the efficiency of solar radiation, sun intensity and temperature variability of the geographical area as a key to climatic issues and solar systems manufacturing.

CONCLUSION

The study explains the optimal sun intensity of Federal Polytechnic Oko at the extension site using the solar power meter (solarimeter) and the temperature of the day was also recorded with mercury -in -glass thermometers. Readings were tabulated and graph where plotted to show the optimal level of sun intensity and solar radiation at the extension site and its environment. This research work will be of great value for the researchers, importers and dealers of solar systems, manufacturers of solar systems and federal government documentation of sun intensity and climatic issues for periodic appraisal use of sun intensity and solar systems in the geographical area.

RECOMMENDATION

The research is also recommended for researcher, importers of solar system, manufacturers of solar system and federal government documentation of sun intensity and climatic issues in the geographical area. The Solarimeter instrument is also advised to be used for the documentation of the climatic influence and in optimization of solar intensities of Nigerian geopolitical zone. Periodic utilization of the solarimeter instrument will help to observe the effect of climatic conditions at every interval of the year. It will also help the government and individuals both private and companies for periodic appraisal use of sun intensity and solar systems.

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