MEASUREMENTS AND UTILISATION OF SOLAR RADIANT ENERGY IN PAKISTAN*

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The paper contains a brief history of the Pakistan National Actinometric Network, describes the instrumentation and summarizes the data collected during the first few years.

Gradual increase in the maximum global radiation has been observed during 1953 to 1956 and is attributed to the dissipation of volcanic dust that was sent up into the stratosphere by the eruption of Mt. Spurr (Alaska) on 9th July 1953. The global radiation received at 1719 m.== asl (Quetta) is reduced by about 17.5 percent in its passage through a turbid atmosphere 1956 m. thick before it is received at 123 m== asl (Multan) not far away on the same latitude (30°12′N). At Quetta diffuse radiation is responsible for 27.4 percent of global radiation.

The empirical relationship $Q/Q_0 = a + b. S/S_0$ is found to hold for each of the four stations in West Pakistan, and the constants show the following logarithmic relationships with the station altitude h:

$$a = 0.6 - 0.05 \log_e h$$
$$b = 0.4 + 0.07 \log_e h$$

A few attempts towards designing of solar cookers and space-heaters made at the Geophysical Institute, Quetta, are also described.

Introduction

Some exploratory measurements of solar radiation were carried out in Baluchistan in as early as 1926 with a view to selecting a suitable site for the establishment of a Solar Physics Observatory in this part of the world.[1] Unfortunately for Pakistan the choice then went to Mt. Brukkoros (17°48′E, 25°52′S) in southwest Africa due to the better "seeing" conditions obtaining there for the study of the solar constant. Thereafter, the first observations for solar radiation were started in this region at the Geophysical Institute of the Pakistan Meteorological Service at Quetta (30°11′N, 66°57′E, 1719 m.asl) in October 1952 and consisted of measurements of instantaneous values of global (sun+sky) and diffuse (sky only) incoming radiation on a horizontal surface with the help of a direct reading solarimeter manufactured by Kipp and Zonen of Holland. The observations were supplemented with the measurements of direct sun radiation on a plane normal to the rays of the sun and in two different wavelength bands employing an actinometer by the same makers. Within a year the output from the solarimeter for global radiation was being fed to a Fielden servograph for continuous recording of the energy income during the day time. In August 1955 the servograph was replaced by a single point Cambridge recorder (Model B) and the availability of another recorder helped to start the continuous recording of the diffuse component as well. For this purpose a thermopile of another solarimeter was exposed to the sky radiation and was kept shielded from direct rays from the sun throughout the day with the help of an occulting ring described in the following pages. Towards the close of 1956 a Jules Richard pyrheliograph on equatorial mounting and a few albedometers and actinometers of soviet manufacture were received through the UNESCO and a six-channel Elliottronic potentiometer recorder took over the simultaneous recording of all the components on the same chart.

The National Actinometric Network

While these developments were taking place at the redesignated Central Actinometric Station at Quetta, efforts continued for the establishment of a National Actinometric Network comprising, in addition, the supplementary stations at the Pilot Balloon Observatories at Karachi (24°54′N, 67°08′E, 22 m.asl), Multan (30°12′N, 71°26′E, 123 m. asl) and Peshawar (34°00′N, 71°30′E, 352 m.asl) in West Pakistan and at Dacca (23° 46′N, 90°23′E, 8 m.asl), Chittagong (22°21′N, 91°50′E, 27 m.asl) and Cox's Bazar (21°26′N, 91°58′E, 3 m. asl) in East Pakistan. As more and more instruments became available, the first two supplementary stations went into operation during 1956, the third in 1957, Dacca and Chittagong in 1958 and Cox's Bazar in 1960. Instruments at all the stations were inter compared and recalibrated against a working standard maintained at the Central Actinometric Station once every year. Records from all stations continued to be sent in original to Quetta for analysis.

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Global Radiation at Quetta.—The Geophysical Institute at Quetta is located on the slopes near the foot of the Chiltan Range which runs almost from south through west to north of the buildings subtending on occasionsat vertical angles of about 20° at the site of radiation instruments. Fig. 1 shows the portion of the celestial dome and the solar paths in different seasons cut off by the surrounding hills. The outermost circle is the celestial horizon and the concentric arcs are altitudes in steps of 10° from the horizon to the zenith at the centre of the diagram.

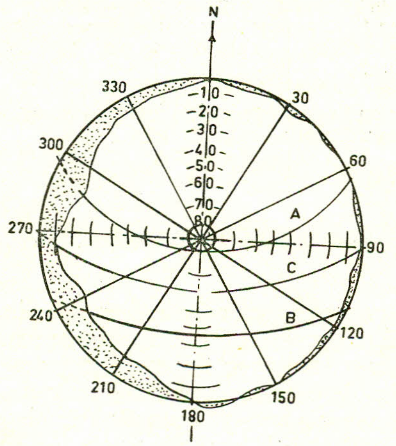

Fig. 1.—Exposure conditions at the Actinometric Station at Quetta. Curves A and B are solar paths at summer and winter solstices respectively, while C is the path at the equinoxes. The shaded area is the part of the celestial dome cut off by the hills.

Fig. 2 represents the monthly mean daily global radiation at Quetta during the five-year period of September 1953 to August 1958. The thick triangular points are the values reported by Ramdas and Yagnanarayanan [2] for Quetta. The actually recorded variation compares favourably with their computed variation from month to month except for the slightly smaller amplitude of variation from the maximum in summer to the minimum in winter for their values. The observed values during the major part of all the five years are somewhat lower than the computed values. This is due to the hilly terrain effect shown in Fig. 1 which cuts down the global radiation by about 1.8% in June to a little over 3% in December. The anomoly of values during July and August of the later two years being significantly higher than the previous three years is due to the fact that abnormally cloudless skies prevailed during these months in 1957 and 1958.

In Table 1 are listed the maximum (Q_x) and minimum (Q_n) values of global radiation per

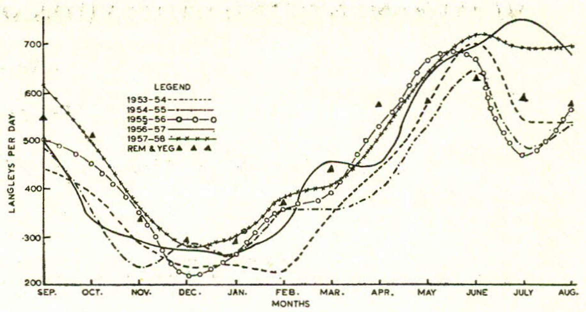

Fig. 2.—Monthly mean daily global radiation at Quetta during September 1953 to August 1958.

day recorded during each month in the 5-year period. Comparing Q_x of corresponding months in different years it is noticed that the values in practically all the months of the years 1953-55 are significantly lower than the values recorded during the years 1956-58. In most cases the maximum energy income per day, supposed to be recorded on a cloudless day with the least of haziness in the lower atmosphere, gradually increases from year to year upto 1956 or 1957. This effect is not so pronounced in the monthly mean daily values of Q plotted in Fig. 2 since ideally cloudless and hazeless days may be very few and the gradual increase effect brought out by Q_x for such days is likely to be superposed by such other factors as predominantly affect the monthly means. The consistency in the mean values does, however, help to remove any doubt about calibrational or computational error leading to the observed rise in Q_x from year to year. It would, therefore, appear that the unexpected behaviour of Q_x is real.

This could be due either to a corresponding increase in the energy output of the sun from 1953 onwards or to the transparancy of the terrestrial atmosphere gradually improving. The first possibility is ruled out, since it is well known that the sun is radiating energy at an almost constant rate with only insignificant variations due to solar prominances and sunspots. Moreover, in the years 1953-54 the sun passed through a phase of minimum sunspot cycle and, if the sunspots were at all to affect the global radiation at the earth's surface, there should have been more incoming radiation during 1953-54 followed by a gradual decrease in subsequent years when the number of sunspots increased. The second possibility appears more plausible and is supported by the findings of Fritz [3], Enger and Fritz [4] and Arakawa and Tsutsami.[5] They reported decreased global radiation during 1953-54 at widely separated stations in the Northern Hemisphere. It may be

TABLE I.—MAXIMUM AND MINIMUM GLOBAL RADIATION RECORDED ON ANY DAY AT QUETTA DURING DIFFERENT MONTHS OF THE 5-YEAR PERIOD.

Months	Years 1953		1954		1955		1956		1957		1958	
	Q_X	Q_N	Q_X	Q_N	Q_X	Q_N	Q_X	Q_N	Q_X	Q_N	Q_X	Q_N
January	—		285	128	381	150	449	20	558	144	411	113
February	—		403	96	387	247	538	97	606	105	430	131
March	—		432	142	488	95	609	81	672	192	512	169
April	—		556	232	483	278	696	258	597	248	644	179
May	—		675	407	656	363	761	579	715	344	798	187
June	—		733	558	745	358	802	493	830	604	822	467
July	—		672	301	530	215	653	213	807	600	796	452
August	—		601	413	619	272	635	410	754	493	795	547
September ..	444	413	578	407	562	416	564	308	664	501	—	—
October	452	319	—	—	510	417	597	183	621	418	—	—
November ..	375	171	344	142	416	213	469	236	443	112	—	—
December	312	118	316	206	315	28	467	134	358	81	—	—

recalled that an eruption of a volcano at Mount Spurr, Alaska, on 9th July 1953 sent a dark cloud of ash and vapour into the stratosphere (Juhle and Coulter,[6]) where the volcanic dust would have got trapped in the inversion layer and could have spread over wide areas of the globe. Vancouleurs[7] had suggested investigation for its spread through pyrheliometric measurements in the different parts of the world. The decrease in solar radiation following the eruptions of Krakatoa in 1883 and Katmai in 1912 are well known.

It therefore, so happened most likely that the recording of solar radiation was started at Quetta when the incoming global radiation was at its lowest ebb due to the concentration of the volcanic dust in the stratosphere of the Northern Hemisphere. As the dust gradually dissipated and settled down over a period of a few years, the incoming radiation gradually increased showing the unusual trend in Q_X at Quetta from 1953 until 1956 or 1957 before reaching a steady level.

Global Radiation at Karachi, Multan and Peshawar.—As already mentioned at the beginning, continuous recording of global radiation was started at Karachi and Peshawar from September/October 1956, while that at Multan from March 1957. The instrumentation consisted of solarimetric thermopile Nos. 833-828 and 829 at the respective stations connected to a single-point Cambridge Recorder (Model B) at each station with 50 ohm resistance in series.

The exposure of the thermopiles at each of these stations was clear of any significant obstacles all round the horizon and more particularly along the whole range of the sun's path from sunrise to sunset throughout the year except for the mast of the P.T. anemorgraph at Peshawar which would shade the thermopile from direct rays of the sun for a few minutes around noon during winters. This did, however, not cause any serious difficulty in the interpolation of the values on the solarigrams.

Fig. 3 shows the plotted monthly mean of daily global radiation at each of these stations for the two-year period September 1956 to August 1958. While the curve for Multan starts from March 1957 for reasons given earlier, the curve for Peshawar shows a break from March to August 1957 caused by instrumental breakdown. The values for Quetta for the same period have also been plotted again in Fig. 3 for comparison. While Multan and Peshawar, like Quetta, show one maximum in summer and one minimum in winter, the march of the monthly means at Karachi is peculiar in that it shows a secondary minimum in July and weak secondary maximum in October each year. This is due to Karachi experiencing maximum cloudiness during July and the clearest skies during October. Similar variations have been reported for Mimi and New Orleans in the U.S.A.[8] When the sun is near the southernmost position (our winter) the incoming radiation is very fairly distributed according to the latitude of the stations—Karachi receiving almost double the amount of solar

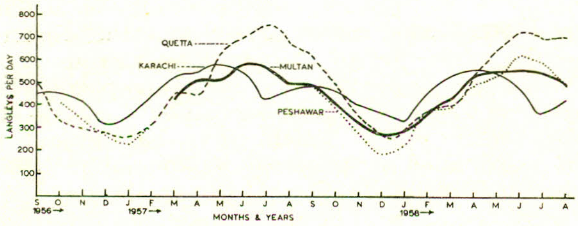

Fig. 3.—Monthly mean daily global radiation at the four stations in West Pakistan during Sep. 1956 to Aug. 1958.

energy received per day by Peshawar. Quetta and Multan, on the same latitude and almost midway between Karachi and Peshawar, receive almost equal amounts of solar energy, the values also lying midway between those of the other two stations during the winters. The significant difference in the energy income at Quetta and Multan during the summers, however, leads one to visualise the important role played by the 1596 m. thicker turbid atmosphere over Multan in reducing the intensity of solar radiation by almost 17·5%.

In Table 2 are listed the monthwise highest and lowest values of global radiation per day as on record for the two-year period for each of the three stations.

TABLE 2.—MAXIMUM AND MINIMUM GLOBAL RADIATION RECORDED ON ANY DAY AT THE THREE SUPPLEMENTARY STATIONS DURING SEPTEMBER 1956 TO AUGUST 1958.

Months	Karachi		Multan		Peshawar	
	Q_x	Q_n	Q_x	Q_n	Q_x	Q_n
January	411	75	350	95	338	39
February	515	252	440	175	460	75
March	594	429	530	143	522	69
April	638	254	618	347	620	67
May	648	471	648	200	734	124
June	610	370	643	348	734	417
July	598	139	654	359	700	187
August	632	236	572	323	584	123
September	552	300	519	467	570	247
October	538	335	458	279	516	134
November	443	311	389	69	371	90
December	392	90	340	56	309	52

Empirical Relationship between Global Radiation and Sunshine Hours.—More often than not it is necessary to estimate the values of global radiation either for interpolating missing data in a series or for the purpose of estimating global radiation for stations not equipped with solarimeters. The problem has been under investigation since as early as 1919 and Fritz[9] has summarised the findings of Kimball, Angstrom and Haurwitz, all of whom have suggested a relationship of the form, $Q/Q_o = a + b.S/S_o$, between the actual global radiation Q, the maximum possible global radiation Q_o, the actual hours of bright sunshine S, and the maximum possible hours of bright sunshine So, for the corresponding date (or period) at a station. The constants *a* and *b* were found to be different for different stations and their sum was close to unity. Working with monthly means of the parameters, however, Fritz and MacDonald[10] reported a little departure of (a+b) from unity and also an increase in *a* from the eastern to the western coast of the North American continent.

The relationship has been examined for the four stations in West Pakistan utilising the daily values of global radiation and sunshine hours. While the hours of maximum possible sunshine for each station could be worked out for each date from the sunrise and sunset timings for the respective latitudes (barring local orographic effects etc.), the values of maximum possible global radiation have been obtained by the method suggested by Fritz.[11]

The scatter diagram of Q/Q_o *versus* S/S_o has been plotted for each station as in Fig. 4 for Multan. The relationship in each case appeared close to being linear and drawing the best fit straight line through the points resulted in the values of the constants *a* and *b* as listed in Table 3.

It is observed that the constants are greatly influenced by the altitude of the stations with *a* decreasing rather rapidly in the lowest few hundred meters (the turbid layer of the atmosphere) and more gradually in the higher levels. If the altitude of the station is denoted by *h*, then a closer examination of the dependence of *a* and *b* upon *h* reveals the following exponential relationships:

$$a = 0.60 - 0.05 \log_e h,$$

$$\text{and } b = 0.40 + 0.07 \log_e h.$$

It is quite possible that for stations located above the turbid layer of the atmosphere the constants may remain unchanged and may be very close to those obtained for Quetta at 1719 m.asl. It is interesting to note that the sum of the constants, (a+b), also appears to be affected by the altitude

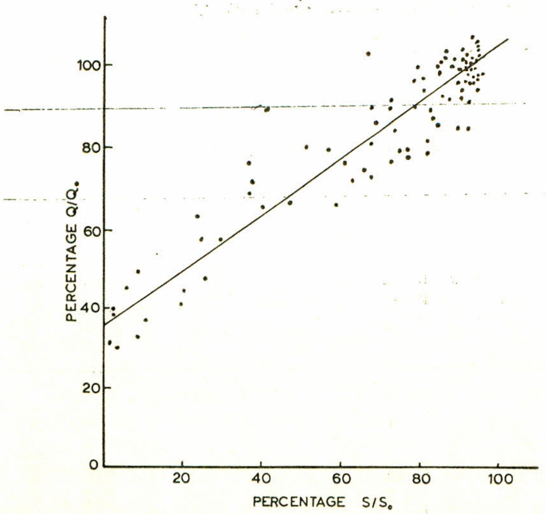

Fig. 4.—Scatter diagram of S/S_0 and Q/Q_0 percentage for Multan.

TABLE 3.—VALUES OF THE CONSTANTS 'a' AND 'b' AT THE FOUR STATIONS.

Stations	Altitude m. asl.	'a'	'b'	(a+b)
Karachi	22	0.46	0.63	1.09
Multan	123	0.35	0.70	1.05
Peshawar	352	0.30	0.83	1.13
Quetta	1719	0.24	0.90	1.14

of the stations although to a much lesser extent. This could as well be accidental and needs confirmation from records for a much longer period.

Frequency Distribution of Global Radiation.—For the design of solar engines, it is often necessary to know the threshold value of global radiation per day for which an engine should be designed so as to be useful over a reasonably good number of days in the year. The purpose of such engines and their efficiency factors achievable would have to be taken into account before a minimum value of desirable global radiation per day can be decided upon. To help the prospective designers, a frequency distribution of the number of days per year when the total incoming radiation is within suitable ranges at each of these stations has been worked out for a typical year and is presented in Table 4. It is seen that an engine designed to respond to a minimum threshold value of 350 ly./day can be used with advantage on 91% days of the year at Karachi and on 79%, 72% and 67% days at Quetta, Multan and Peshawar respectively. Moreover, the days on which the engines can be used are spread over almost the whole year for Karachi and Quetta while the engines will remain idle at the other two stations during two months of the year only. No solar engine can perhaps be designed economically to respond to threshold values of less than 350 ly./day while engines that may work at no less than 500 ly./day incoming radiation will remain idle for the major part of the year everywhere.

Diffuse (Sky) Radiation.—Diffuse radiation is the amount of solar energy received at the surface of the earth due to scattering by gaseous and particulate suspensoids in the atmosphere. It forms a part of the global radiation discussed in the earlier pages. Landsberg [12] has estimated its contribution to the global radiation at 42% for the whole globe. The main factors affecting this contribution should be the latitude and elevation of the station coupled with prevailing atmospheric turbidity and cloudiness of the sky. At Blue Hill Observatory in the U.S.A. 194 m.asl, the mean contribution of the diffuse radiation is reported to be 38% while at Mt. Evans, about 4300 masl. its contribution on a cloudless midsummer noon has been found to be as low as 4 to 5% only. [13] A knowledge of the diffuse component of incoming solar radiation is of prime interest now in almost all fields of our activity.

Continuous recording of the diffuse radiation was started at Quetta in September 1955 with a solarimetric thermopile kept shaded from direct rays of the sun throughout the day by an occulting ring shown in Fig. 5. The diameter of the occulting ring is 28.3 cm. and is made of sheet metal 4 cm. wide. It is mounted on a slotted base sloping from north to south making an angle with the horizontal equal to the latitude of the station. The thermopile with its plane horizontal is placed at the axis of the cylindrical ring with the help of another support mounted on the same base. By adjusting the position of the ring on the sloping base according to the declination of the sun the thermopile is kept shaded from direct rays of the sun throughout the day and all the year round. This adjustment has to be carried out every third or fourth day depending upon the rate of the change of solar declination. The whole unit including the inside of the occulting ring was initially painted white and, on the presumption that the reflected diffuse and emitted radiation from the inside of the ring onto the thermopile would almost compensate for the diffuse radiation cut off from the portion of the sky obstructed by the ring itself, no allowance was made to the actually recorded values of diffuse radiation. The inside of the occulting ring was, however, painted black before the commencement of the International Geophysical Year. Due allowance was thereafter necessary, which came to increasing

TABLE 4.—FREQUENCY DISTRIBUTION OF DAYS RECEIVING DIFFERENT AMOUNTS OF GLOBAL RADIATION.

Range of Global Radiation (ly/day)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	%
Karachi														
650 or more													—	—
500 or more		1	29	27	27	19	12	14	11	11			151	42
350 to 499	16	26	2	3	3	10	12	13	19	19	27	28	178	49
200 to 349	15	1			1	1	6	4		1	3	3	35	9
<200							1						1	—
Multan														
650 or more							1						1	—
500 or more				26	27	26	29	22	16				146	40
350 to 499	1	17	28	4	3	3	2	8	14	28	9		117	32
200 to 349	28	10	3		1	1		1		3	18	25	90	25
<200	2	1									3	6	12	3
Peshawar														
650 or more					8	17	4						29	8
500 or more			7	19	21	23	28	24	17	1			140	39
350 to 499		23	15	7	5	7	2	3	11	24	5		102	28
200 to 349	20	2	8	3	4			2	2	4	18	16	79	21
<200	11	3	1	1	1		1	2		2	7	15	44	12
Quetta														
650 or more					17	22	29	25	4				97	27
500 or more			4	21	26	28	31	30	30	19			189	52
350 to 499	9	22	17	5	3	2		1		12	23	7	101	27
200 to 349	18	5	9	3	2						5	16	58	16
<200	4	1	1	1							2	8	17	5

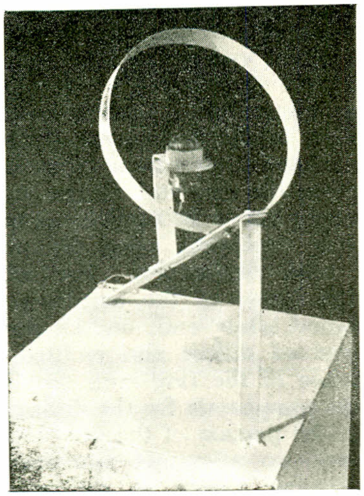

Fig. 5.—A close-up of the occulting ring for diffusograph designed at Quetta.

the values of diffuse radiation by about 5% on the average.

In Fig. 6 are plotted the weekly mean daily diffuse radiation, the weekly mean daily global radiation and the weekly mean percentage ratio of diffuse to global radiation for one complete year begining 3rd September 1955 (36th week of the calender year). Although the curves are irregular due to the small quantity of the data, the march of diffuse radiation shows a definite mean maximum during summer (320 ly./day recorded on 26th June and 3rd July 1956) and a mean minimum during winter (32 ly./day recorded on 5th January 1956) which are consistent with the usually observed maximum haziness of the lower atmosphere over Quetta during summers and the extraordinarily deep blue skies there during the postmonsoon and winter months. The percentage ratio of diffuse to global radiation shows a primary maximum during winter when Quetta

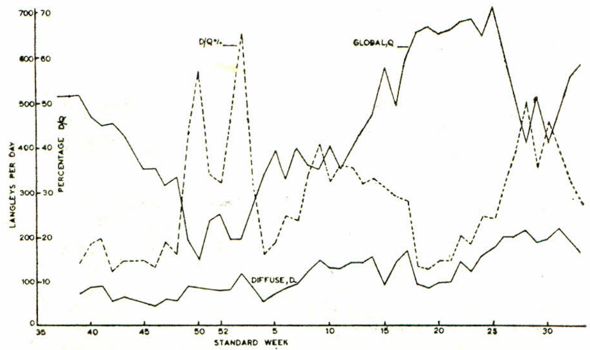

Fig. 6.—Weekly means of daily diffuse and global radiation and their percentage ratios at Quetta.

experiences most of its cloudiness and rainfall under the influence of primary and secondary *Western Disturbances* which move over the area one after the other in quick succession. A secondary maximum of the percentage ratio is to be found due to the cloudiness during the monsoon period. The yearly mean percentage ratio of diffuse to global radiation is found to be 27.4 for Quetta as against 38.0 for the Blue Hill Observatory. As may be expected, the percentage ratio of diffuse to global radiation shows a very close negative relationship with the percentage ratio of the actual hours of bright sunshine (S) to the hours of maximum possible sunshine (S_0). The interdependence is amply demonstrated in Fig. 7.

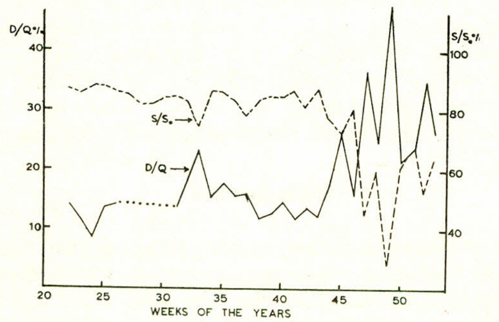

Fig. 7.—Weekly march of D/Q and S/S_0 percentages at Quetta; June to December 1957.

wherein weekly means of the two ratios have been plotted for the period June to December 1957 (22nd to 2nd week of the next year). The relationship is close to logarithmic as indicated by Fig. 8 in which the percentage of S/S_0 has been plotted against the logarithm of percentage D/Q.

The scatter of the points may be attributed partly to the mean values having been worked out for rather too short periods and partly to the inherent limitation of the Campbell-Stokes Sunshine Recorders in responding faithfully to the sunshine. Even on cloudless days the errors due to haze, mist or fog near sunrise or sunset may be quite significant.

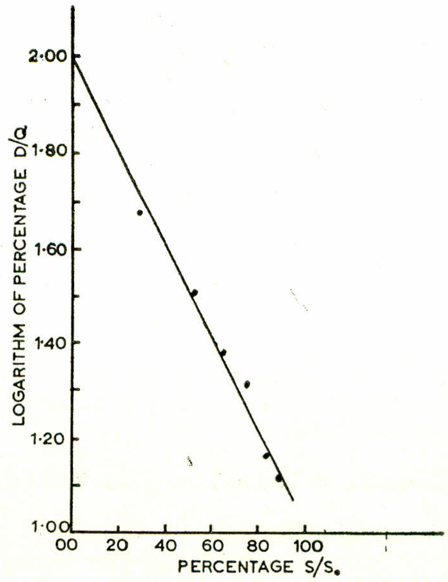

Fig. 8.—The logarithmic relationship between D/Q and S/S_0 percentages for Quetta; June to December 1957.

Accuracy of the Data.—The calibration of solar radiation instruments is effected by taking simultaneous observations with the instrument under calibration as well as with a *Standard Pyrheliometer* when the sun is high in the sky on a cloudless day with the least of haziness. In the absence of adequate resources for calibration of the instruments in Pakistan against a *Primary Standard*, one of the brand new thermopiles, for which suitable "efficiency" certificates were supplied by the manufacturers specifying the E.M.F. generated at the terminals by an incident radiation of 1 ly./mt., was used as a *Working Standard* and the intensity scale reading on the charts of the recorders for different combinations of the other thermopiles and recorders were calibrated with reference to corresponding incoming radiation indicated by the *Working Standard*. The E.M.F. generated at the terminals of the thermopiles was read on a Pye precision potentiometer. One division on the time scale of the chart should correspond to exactly 60 minutes when the frequency of the AC supply to the motor of the Cambridge Recorder is 50 c/s. This, however, varied slightly at each station depending upon the fluctuations in the AC supply at that station. At Karachi one division on the time scale would on the mean represent 59 minutes while at Multan it would be covered in 60.4 minutes. For

Peshawar the mean was exactly 60 minutes. A closer study of the records showed that the chart movement could gain or lose time by as much as one minute per hour, the average being about 10 minutes per day. Therefore, while evaluating the energy income, a correction depending upon the actual gain or loss by the chart on a particular day for each station was applied.

Placing the accuracy of the calibration constants of the solarigraphs within 1% and the computational errors almost negligible, an overall accuracy limit of about 5% for values obtained from the solarigrams for each day can be safely assumed and should be considered satisfactory in view of the lesser accuracy inherent in the decoding of the autographic records.

Utilisation of Solar Energy in Pakistan

The first experiments for the utilisation of solar energy in Pakistan were carried out during 1955 at the Geophysical Institute, Quetta, by a team of officers of the Pakistan Meteorological Department. A type of solar-cooker, both cheap and easy to make, was designed making use of the soft clay available in the neighbourhood of the city. The clay was moulded to form a paraboloid inside an ordinary wooden case and small pieces of polished metal sheet cut from the 4-gallon kerosene oil containers were pasted on the surface of the paraboloid. The cooking pot was placed at the focal point of the paraboloid by suspending it from a wooden gallow placed due north of the cooker so as to avoid its shade falling on the unit. Cooking could proceed successfully by an appropriate alignment of the solar-cooker to 'face' the sun. The main drawback of the cooker was its unmanouverable weight due to about 1 cwt. of clay necessary for making a paraboloid of the optimum size that could catch sufficient amount of solar energy.

Two years later a pilot solar space heater was designed to supplement the short supply of indiginous steam coal for warming rooms during the cold but sunny days of winter at Quetta. It consisted of a cheap wooden frame about 5′×4′×6″. The bottom was covered with black mat and the top was covered with a transparent glass sheet. Along one of the top edges there was an opening of about an inch for the air to enter the box. The space between the top and the bottom was again partitioned by placing another glass sheet of equal size all along the centre of the box, but with the inch-wide gap at the end opposite to the opening along the top edge interconnecting the two compartments. From the underside of the first end an insolated hose-pipe connected the space heater to a suction fan fitted for blowing the air into the room through one of the removed window panes. The space heater at work is shown in Fig. 9.

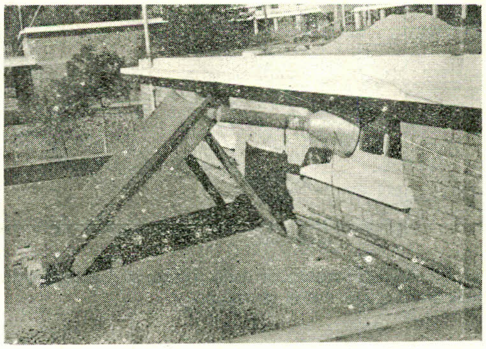

Fig. 9.—The solar space heater at the Geophysical Institute, Quetta.

The space heater was placed "facing" the sun along the plinth of the south wall of a building and with the edge having the opening for air entrance placed at a higher level. When the suction fan was switched on, the outside cold air was sucked into the box, double circulated and heated by the sun's rays. There from the heated air was blown into the room to raise its temperature. The space-heater was operated at Quetta for over two months and it was found that the air temperature within the room (12′×12′×10′) rose by about 5°F above the air temperature out of doors while the suction fan operated on a sunny day under the grip of a polar cold wave. Subsequently, the sheets were replaced with black cloth and it was found that the temperature rise was not significantly different. This unit was much cheaper and more convenient to handle.

Conclusions

A gradual increase in the monthly maximum global radiation from year to year, 1953 onwards, at Quetta shows that the volcanic dust injected into the stratosphere by the eruption of Mt. Spurr (Alaska) in July 1953 had spread to as far south as 30°N and it took three to four years for the dust to dissipate or settle down.

The annual variation of global radiation at Quetta, Multan, and Peshawar is consistent with solar declination showing a maximum in summer and a minimum in winter. The variation at Karachi shows a secondary minimum in July and a corresponding maximum in October due to the maximum and least cloudiness at this station during the respective months. In the hot and dry season when the atmosphere is excessively polluted due to turbulence in the lower atmosphere, the 1596 m.

thick layer of the atmosphere between the altitudes of Multan and Quetta, on the same latitude, causes the depletion in global radiation by as much as 17.5%.

The empirical relationship between global radiation and hours of bright sunshine are linear for each of the four stations and are representable by the formula.

$$Q/Q_0 = a + b . S/S_0 \quad (\text{with } a+b \approx 1)$$

The values of the constants are, however, sensitive to altitude of the station——'a' decreasing with increasing altitude——and exponential relationships between them have been established.

Frequency distiibution of global radiation in the different ranges of intensity shows that a solar engine designed for a minimum threshold value of 350 ly./day will be useful during the major part of the year at all the stations in West Pakistan.

The yearly mean contribution of diffuse (sky) radiation to the global radiation is found to be 27.4% only for Quetta. The ratio of diffuse to global radiation is maximum during the winter season when the Western Disturbances are active and during the monsoons. It shows a logarithmic relationship with the ratio of actual sunshine hours to the maximum possible sunshine hours.

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