TESTING SOLAR OVENS AND METHODS OF IMPROVING THEIR EFFICIENCIES

Project Report

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Meaning of Abbreviations

TOG_1	temperature of outer surface of glass cover
TIP_1	temperature of inner region of the pot
TIG_1	temperature of inner surface of glass cover
TIC_1	temperature of inner region of oven
TOP_1	temperature of outer surface of the pot's cover
TSC_1	temperature of inner side of the cover
TBC_1	temperature of the bottom surface of oven
TSP_1	temperature of side surface of the pot
TA	ambient temperature
TP_1	temperature of potato
TIC_2	temperature of inner region of the oven
TSC_2	temperature of side of the inner surface of the oven
TOP_2	temperature of outer surface of the pot
TSP_2	temperature of side surface of the pot
TIP_2	temperature of the inner region of the pot
TGC_2	temperature of bottom surface of the oven
TR	temperatuer of surface of mirror reflection
TOG_2	temperatuer of outer surface of the glass cover
TIG_2	temperature of inner surface of the glass cover
TP_2	temperature of potato

INTRODUCTION

Since the oil recession in 1973, the whole world has become increasingly concerned about finding alternative energy sources.

The oil crises has put many countries into big economic shambles to the extent that their economic recovery is still uncertain in the next few years.

While the world's energy demands are increasing daily, the future for conventional fossil fuels is not bright. Forecasts show that from the year 2000 fossil fuel reserves are going to be in decline. Thus, the search for renewable energy sources is very essential if mankind and her industries are to continue to survive.

The impact of the energy crisis for the developing countries is more pronounced than the industrialized countries which have greater purchasing power. However, most of these developing countries have good natural resources which can be developed, with little effort, into other forms of energy sources.

Most developing countries, on the other hand, depend largely on wood as fuel for cooking. However, as the demand for firewood and charcoal increases, the rate of destruction of the forest increases if nothing is done at the same time to cultivate fast growing species to replace those being harvested.

Everywhere in the world almost at some time of the day, the sun shines. Solar energy is "free". It is one of the cheapest and cleanest renewable sources of energy which, if developed very well, would provide much of our energy requirements and also ease most women of developing countries from the energy and the time put into the search for firewood. In order to preserve the beautiful green surroundings around us, much attention needs to be given to developing solar energy which is almost available always and everywhere on this earth.

The objective of this project was to test how efficient some already designed and built solar cooking devices were compared to the two solar ovens and suggest ways by which they can be improved.

EXPERIMENTAL

Some thermocouples were made from copper and constanton wires. Two aluminum cooking pots, each with a cover, were first primed and about two hours later were painted black.

Each of the box ovens under investigation was provided with a pot. The smaller oven was of rectangular modern frame with fibre glass insulation. The black painted metallic absorbing surface was rectangular in cross-section. The cover of the oven was rectangular double-glazing glass. For the purpose of higher temperature, this oven was provided with a mirror reflector.

Similarly, the bigger oven was of rectangular wooden frame. In the same manner, between the wooden frame and the absorbing tray was a fiber glass insulation. This oven was, however, not provided with a reflector.

The thermocouples were inserted onto some specific points of the ovens and also of the cooling pots. The wires were then connected to a temperature recorder.

The solar ovens were set side by side in the sun but not at the same time. The ovens were first tested when there was air (unloaded oven) in the pot. Later, investigations were made for the ovens when some equal quantity of water was measured into each pot in the ovens. Under similar investigation, some potatoes were cooled in each of the pots in the ovens. Average temperatures were calculated from the result of the temperature recorder.

Direct solar radiations were measured with a pyrometer which was placed by the ovens. On the average, the experiments were performed for a period of about six hours.

The experimental results are tabulated in Tables 1-6.

RESULTS AND DISCUSSION

The experimental results are summarized in Tables 1-6. On the average each test took about six hours to run and the general observation is that there is an increase of temperature with time for each experiment. However, the rather high

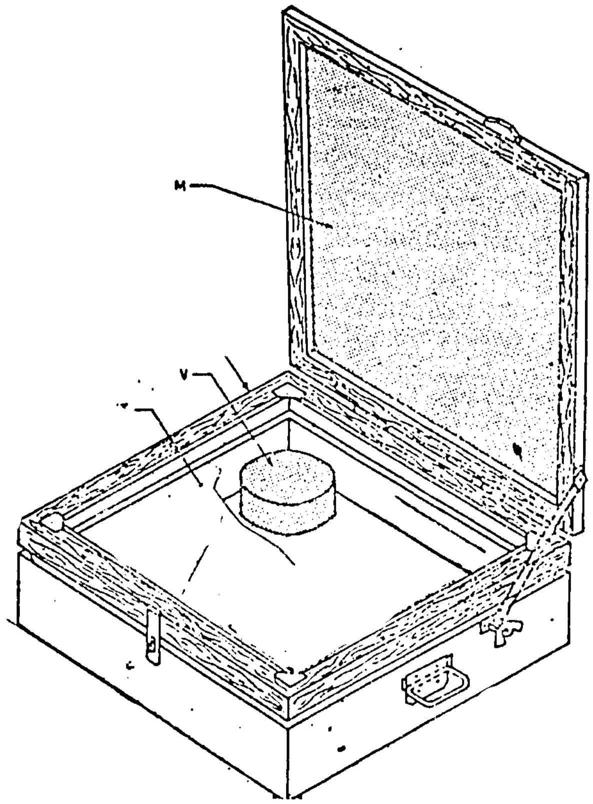

Fig. 1 BOX TYPE SOLAR OVEN

M mirror reflector

G double glass cover of wooden frame

V cooking pot

T absorber plate

O outer box

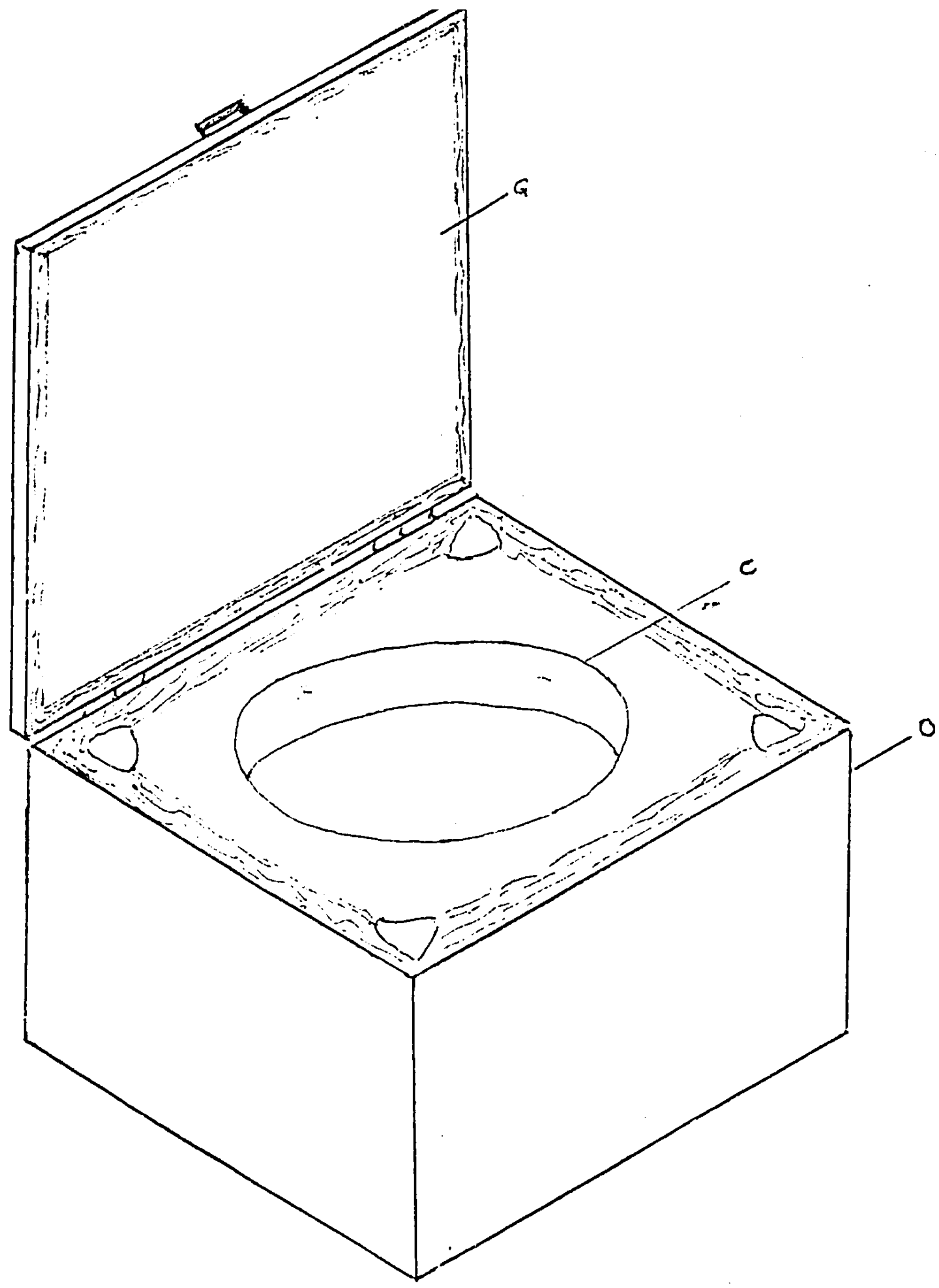

Fig. 2. Box Type Solar Oven (without reflector).

G - double glass cover of wooden frame
C - Cylindrical shape absorber
O - Outer box

Table 1. Average recorded temperatures at time intervals for big oven with no load.

Time (mins)	T_{OGI} (°F)	T_{IPI} (°F)	T_{IGI} (°F)	T_{OGI} (°F)	T_{OPI} (°F)	T_{SCI} (°F)	T_{BCI} (°F)	T_{SPI} (°F)	T_A (°F)
30	149	196	149	200	130	73	86	90	69
60	180	254	209	252	196	78	114	119	70
90	221	266	231	263	221	80	137	145	73
120	217	291	231	284	225	80	151	159	71
150	216	284	236	285	236	81	171	181	79
180	234	288	251	282	251	80	193	208	80
210	230	281	253	282	246	80	209	215	83
240	226	310*	249	311*	247	82	222	227	75
270	236	267	255	268	247	81	244	245	80
300	245	277	261	275	247	84	262	258	80
330	250	294	257	292	240	85	269	263	83
360	241	286	250	287	232	78	268	266	85
390	240	285	248	283	226	82	273	270	84
420	256	262	260	262	244	84	271	264	86
450	263	230	272	238	252	87	268	268	85

Wednesday 04/13/83
Starting time: 0840 HRS
Finishing time: 1610 HRS
*Higher temperatures than expected

Table 2. Average recorded temperatures at time intervals for big oven with some water.

Time (mins)	T_{OGI} (°F)	T_{IPI*} (°F)	T_{IGI} (°F)	T_{ICI} (°F)	T_{OPI} (°F)	T_{SCI} (°F)	T_{SCI} (°F)	T_{SPI} (°F)	T_{A} (°F)
30	128	121	122	61	114	48	86	96	57
60	164	165	155	157	144	50	116	127	50
90	124	207	190	196	159	50	143	154	59
120	229	242	220	229	206	73	167	179	57
150	257	267	246	259	229	72	190	206	61
180	278	284	266	280	246	70	212	221	64
210	295	294	279	287	261	74	232	237	60
240	295	291	281	288	271	74	248	249	66
270	293	289	281	285	280	76	260	258	68
300	288	283	282	278	282	78	277	266	71
330	280	287	279	284	283	81	273	271	71
360	278	279	277	277	275	81	265	273	68
390	289	258	285	254	274	78	277	271	71
420	281	235	282	222	267	81	273	267	71
450	263	206	269	202	258	81	265	259	71

Tuesday 04/19/83
Starting time: 0825 HRS
Finishing time: 1610 HRS
Initial volume of water: 250 ml
Final volume of wter: not measured
*Average temperature of water

Values recorded in Table 1 for the average temperature of inner regions of the pot and that of inner regions of the oven could possibly be the values registered when the thermocouples instantly touched the bottom of the pot and the black absorbing metallic tray. This could have been possible because the thermocouples, in the case of the pot, was only suspending in the pot through a hole drilled through the lid. Likewise, the thermocouple for the inner region of the oven was also suspending.

In Table 4, there are no values for the average temperature of the side of the inner surface of the oven. These experiments were carried out at the same time when lecture was in progress, therefore, most of the the time the equipment was set up unattended until there was a break. Thus, in this particular case it was only when the experiment was over that it was realized that the thermocouple had come off the inner surface of the oven. The sticker had become weak.

Some 250 ml of water was put into the pot of each of the ovens. However, when the experiment was over, the quantity of water left was only measured from the small oven. It was rather too late to have noted the amount of water left in the case of the big oven. The pot had been cleaned up already by a co-worker.

It can be seen that some of the average recorded temperatures, when the ovens were tested for water, exceed 212°F (100°C), Tables 2 and 5, the temperature at which water boils. These rathert abnormal values might have been recorded when the thermocouples were touching the inner bottom surface of the pot instead of suspending in the hot water to have registered the real temperature of the water. The length of mark of the thermocouple entering the pot might have been too long.

In Tables 3 and 6, essentially, the average recorded temperatures of the potatoes for the small oven appreciable exceed those for the big oven. This is evidenced by the use of mirror reflectors for the small oven which helped to increase the temperature of the oven.

In Tables 2 and 5, results indicate that the average recorded temperatures of the center surface of the glass cover of each oven are higher than the values recorded for the bottom surface of the oven. This result is rather unexpected and probably might have come about as a result of the fact that there was condensation on the inner surface of the glass cover of each oven and this might have reduced the transmissivity of the glass.

In Figure 3, the trend of the curves are in uniformity with the fact that as we go from the solid to the gaseous state, the binding forces between the molecules of matter reduce accordingly. Within the same period of time, the temperature rise was lowest for potato but higher for air.

This trend is unfortunatelyu not well observed in Figure 4. Probably, the above effect might have been observed after seven hours from the starting time. As can be seen from the graph, afer 432 minutes, the temperature of the air begins to increase with respect to that of water. However, again there is some sign of abnormality in the sense that we have the temperature of the water rising as much as 268°F which will be rather unusual under normal circumstances.

In trying to find how fast the transmission of the sun's energy through the double glazing glass covers into the absorbing trays causes air, water and potatoes to heat up, the graphs of average temperatures verses time were constructed for the same heating material in each of the ovens.

In Figures 5 and 6, respectively, air and water heated faster in the big ovens. However, Figure 7 shows that the potatoes heated faster in the smaller oven. In Figure 5, it can be seen that after about 426 minutes, more heat was being gained by air in the smaller oven than in the big oven.

Essentially, in Figures 5 and 6, there is gradual increase in temperature of air and water in both ovens with the big oven being hotter than the small one. The highest temperature was recorded between two and three hours after the start of the experiment for the case when the ovens were unloaded and the value being about 288°F. However, with water, the highest temperature was recorded between

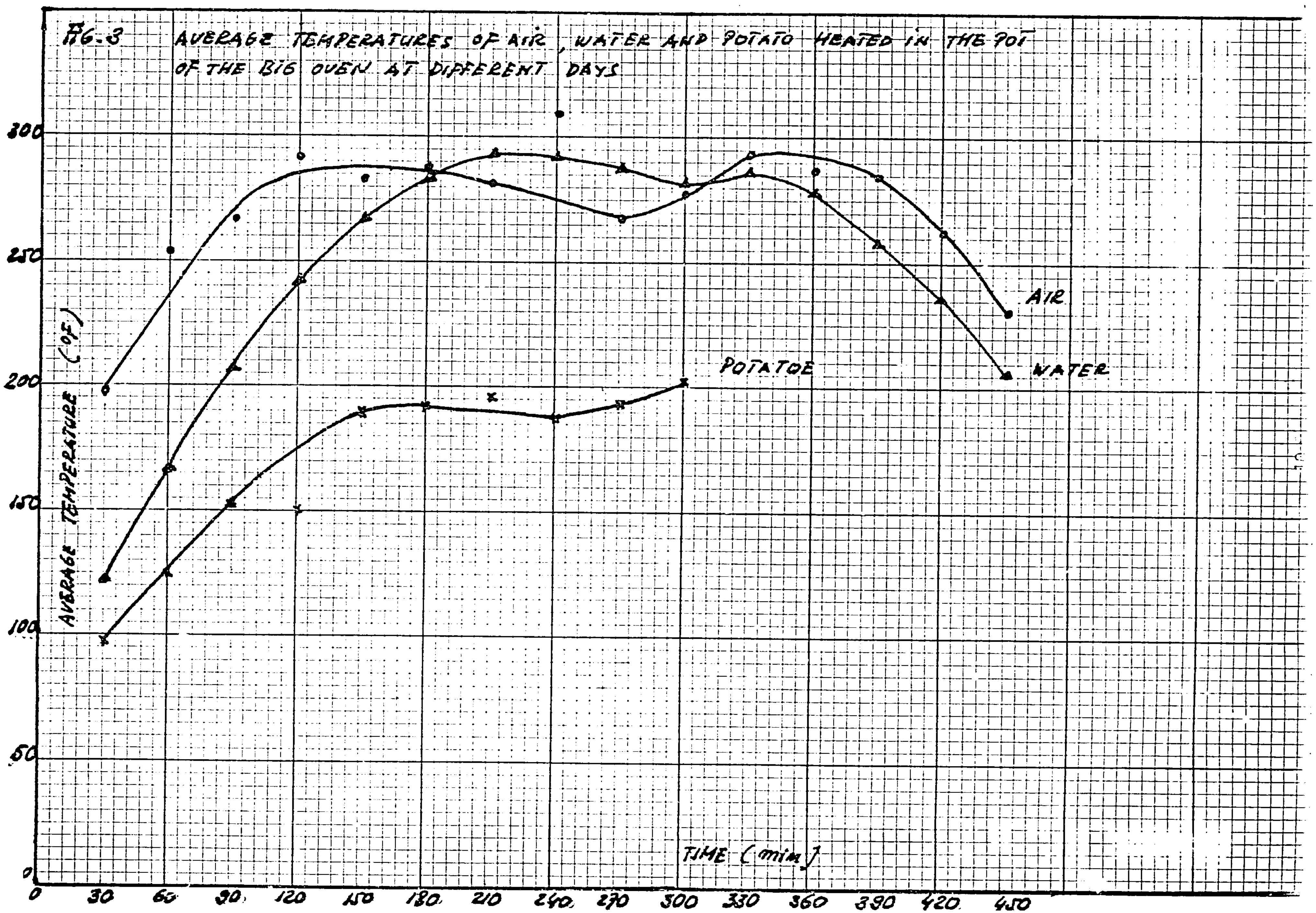
FIG-3 AVERAGE TEMPERATURES OF AIR, WATER AND POTATO HEATED IN THE POT OF THE BIG OVEN AT DIFFERENT DAYS
AVERAGE TEMPERATURE (°F)
300
250
200
150
100
50
0
TIME (min)
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
AIR
WATER
POTATOE

Table 3. Average recorded temperatures at time intervals for big oven with boiling potatoes.

Time (min)	T_{OGI} (°F)	T_{IPI*} (°F)	T_{IGI} (°F)	T_{ICI} (°F)	T_{OPI} (°F)	T_{SCI} (°F)	T_{BCI} (°F)	T_{SPI} (°F)	T_{PI} (°F)	T_A (°F)
30	162	122	129	61	161	81	123	119	98	77
60	197	172	160	115	189	82	149	143	125	77
90	226	196	199	145	212	83	166	168	154	79
120	236	204	210	187	224	84	187	188	150	78
150	216	184	206	169	204	80	195	190	190	76
180	201	183	202	166	197	79	199	192	191	79
210	216	183	206	167	205	77	176	194	196	79
240	198	189	199	174	193	80	196	188	188	79
270	209	203	207	168	214	82	212	201	194	84
300	224	191	211	167	226	84	229	210	201	85

Friday 04/29/83
Starting time: 1020 HRS
Finishing time: 1520 HRS
Mass of potatoes 62g
Volume of water added 350 ml
*Average temperature of water

Table 4. Average recorded temperatures at time intervals for small oven with no load.

Time (min)	T_{IC2} (°F)	T_{SC2} (°F)	T_{OP2} (°F)	T_{SP2} (°F)	T_{IP2} (°F)	T_{BC2} (°F)	T_R (°F)	T_{OG2} (°F)	T_{IG2} (°F)
30	87	-	134	97	94	71	90	81	98
60	112	-	123	120	121	81	115	95	132
90	128	-	153	136	146	89	137	110	164
120	134	-	169	146	162	93	150	115	180
150	134	-	194	163	187	108	169	121	205
180	141	-	139	180	204	107	186	131	226
210	142	-	226	187	213	112	179	133	228
240	139	-	238	178	223	117	199	133	241
270	138	-	250	209	238	120	212	133	258
300	136	-	265	220	250	126	225	135	268
330	139	-	272	225	256	129	232	137	269
360	136	-	270	224	255	129	231	137	275
390	133	-	274	228	259	131	241	137	275
420	140	-	270	224	256	129	236	137	270
450	146	-	271	225	257	128	234	139	271

Wednesday 04/13/83
Starting time: 0840 HRS
Finishing time: 1610 hRS
Refer to Table 1 for the ambient temperature values.

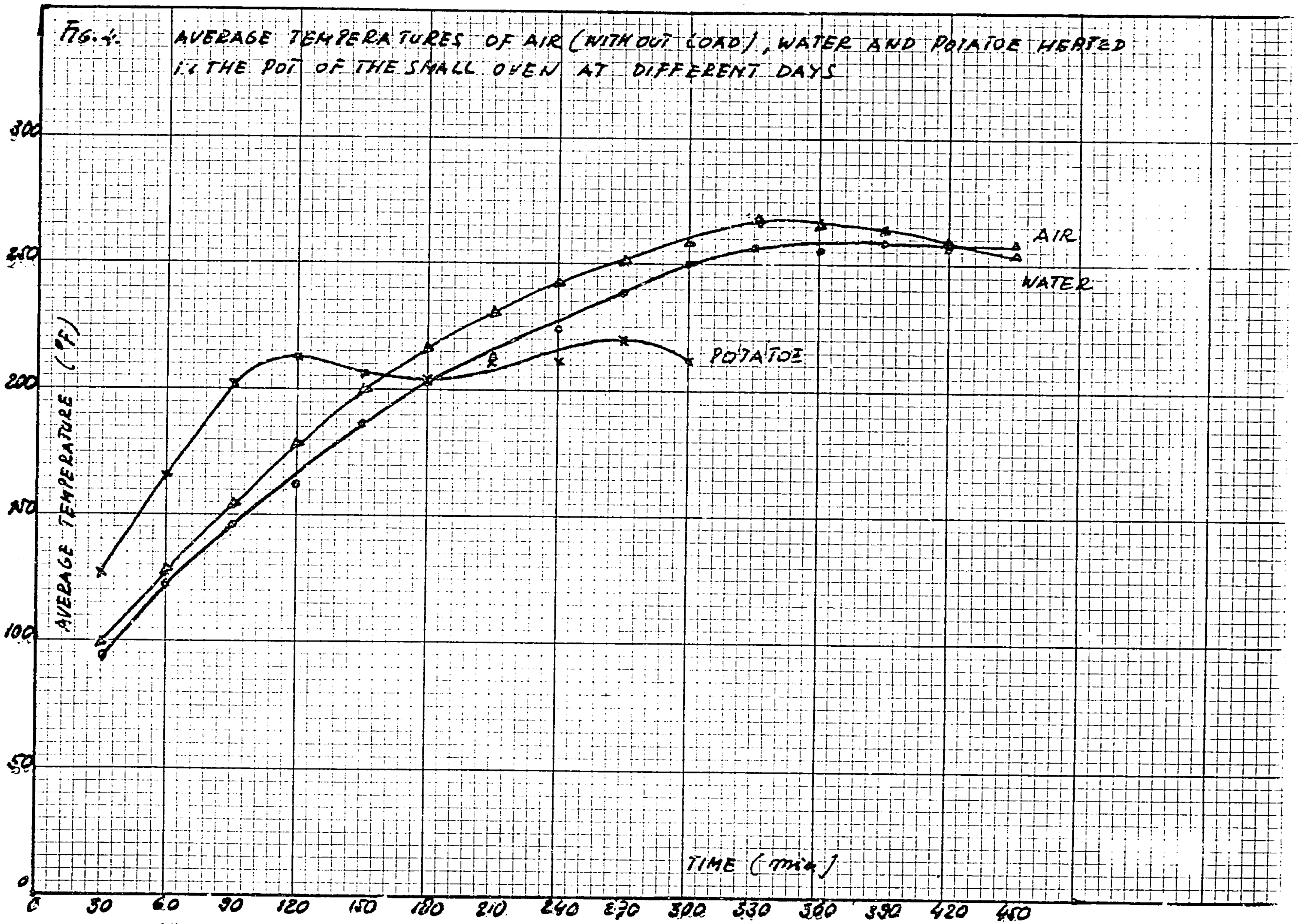

FIG. 4. AVERAGE TEMPERATURES OF AIR (WITHOUT LOAD), WATER AND POTATOE HEATED IN THE POT OF THE SMALL OVEN AT DIFFERENT DAYS
AVERAGE TEMPERATURE (°F)
AIR
WATER
POTATOE
TIME (min)
0
50
100
150
200
250
300
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450

Table 5. Average recorded temperatures at time intervals for small oven with some water.

Time (min)	T_{IC2} (°F)	T_{SC2} (°F)	T_{OP2} (°F)	T_{SP2} (°F)	T_{IP2}* (°F)	T_{BC2} (°F)	T_R (°F)	T_{OG2} (°F)	T_{IG1} (°F)
30	70	89	96	98	98	63	93	165**	104
60	87	115	131	131	126	72	120	198**	141
90	105	137	163	163	154	82	143	196	174
120	119	158	190	159	179	91	164	173	200
150	127	180	214	176	200	97	182	196	221
180	133	201	233	188	216	104	196	214	238
210	140	224	248	201	230	111	209	236	251
240	151	236	260	212	242	118	219	245	262
270	153	253	269	220	250	123	228	282	269
300	153	266	276	276	259	127	233	300	275
330	152	271	280	280	268	126	239	289	279
360	147	270	281	281	265	125	241	281	279
390	150	274	279	231	264	126	240	280	277
420	150	277	274	227	259	125	237	286	273
450	150	272	266	200	253	123	232	287	265

Tuesday 04/19/83
Starting time: 0825 HRS
Finishing time: 1610 HRS
Initial volume of water: 250 ml
Final volume of water: 50 ml
*Average temperatures of water
**Higher than expected
Refer to Table 2 for the ambient temperature values.

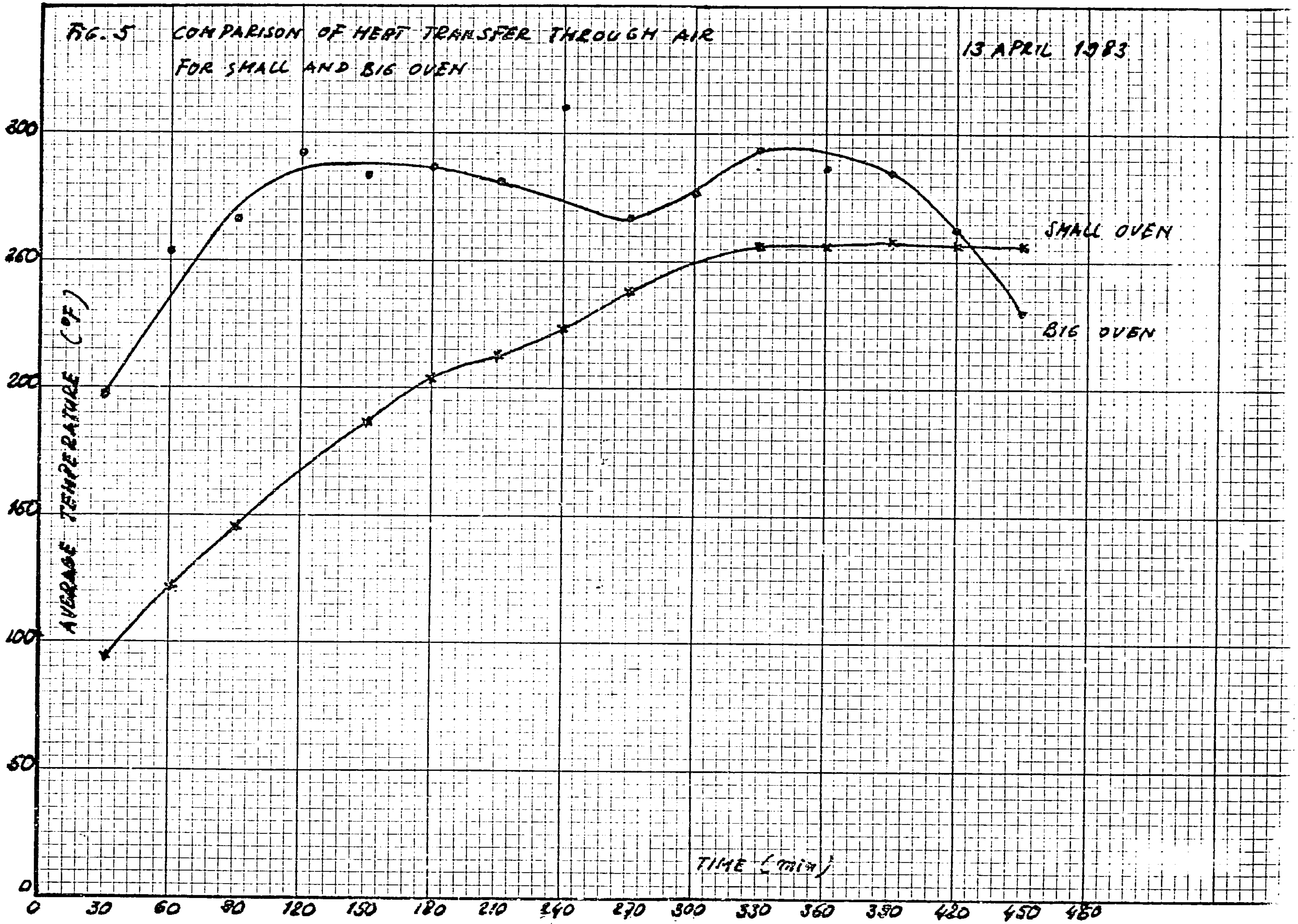

FIG. 5 COMPARISON OF HEAT TRANSFER THROUGH AIR
FOR SMALL AND BIG OVEN
13 APRIL 1983
AVERAGE TEMPERATURE (°F)
TIME (min)
SMALL OVEN
BIG OVEN
0
50
100
150
200
250
300
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480

three and four hours after the start of the experiment and the value being about 295°F. For the case when some potatoes were being heated, the highest temperature was recorded between about four and five hours from the starting time and being about 220°F.

The general characteristic of the curves of Figures 5, 6 and 7 is that from the beginning there is a general increase in temperature of the material being heated; then there is a sudden fall in temperature within the same period of time after when gradually the temperature rises up again and then finally falls as the intensity of the sun reduces in the latter part of the afternoon.

This effect might have been due to the fact that the covers of the ovens were occasionally opened to find out whether or not the thermocouples inside the ovens weres still in place and also the lide of the pots were also removed to find out how the material inside the pot was. There was condensation on the inner surface of the cover of the ovens so occasionally this was also cleaned off.

By doing as stated above, some heat might have been lost from the ovens and which naturally might have caused a sudden fall in the temperature of the materials being heated.

EFFICIENCY OF OVENS

Generally, the idea about efficiency of a piece of equipment depends upon the area of interest of the researcher with respect to the operation of the equipment. In our work, our interest was directed towards finding how fast some quantity of materials will heat up in two box-type solar ovens.

On three different days, air (when oven is unloaded), water and potatoes were respectively tested in the ovens. Results (Figs. 3 and 4) indicated that relatively, it took less time, about 60 minutes, for the air in the big oven to be heated to about 285°F as compared to about 258°F in about 360 minutes for the small oven. However, potatoes heated up faster in the small oven than in the big oven.

Within the time period of about 60 and 100 minutes, the temperature rise for potatoes was about 45°F in the small oven as compared to about 39°F in the big oven. Comparison would not be possible for the maximum temperature reached by water in either oven because this temperature exceeded 212°F, the boiling point of water.

Evidence that the big oven heated faster is suggested by Figure 5. On 13 April 1983, after 120 minutes of the starting time, the temperature of air in the small and big ovens rose to about 285°F and 167°F, respectively.

About 348 minutes after the start of the experiment, maximum temperatures, 295°F and 256°F, occurred respectively in the big and small oven for air.

On 19 April 1983, between 30 and 90 minutes, when the highest temperature of water was below 212°F water showed higher temperature rise in the big oven than in the small one. Potatoes, on the other hand, showed a faster temperature rise (Fig. 7) in the small oven.

The small oven had rectangular shaped absorbing trays whereas the big one had a cylindrical cross sectional absorbing compartment. Apart from the double glazing glass cover in each of the ovens, the small oven was provided with a mirror reflector.

The observation was that during heating of a material, there was much condensation on the surface of the glass cover for the small oven than for the big oven. Even though some pieces of silica gel were placed in the ovens, the condensation did not reduce to any appreciable extent.

The small oven was rather shallow, the big oven was bulky and deep. Probably this part of the design (deepness) prevented more condensation taking place on the surface of the cover. Obviously, the volueme of hot air in this oven was bigger and which would cause a similar kind and size of material to heated up faster than in the oven.

Water vapor on the surface of the glass can reduce the transmissivity of the glass. On the average, materials in the big oven (without mirror reflector)

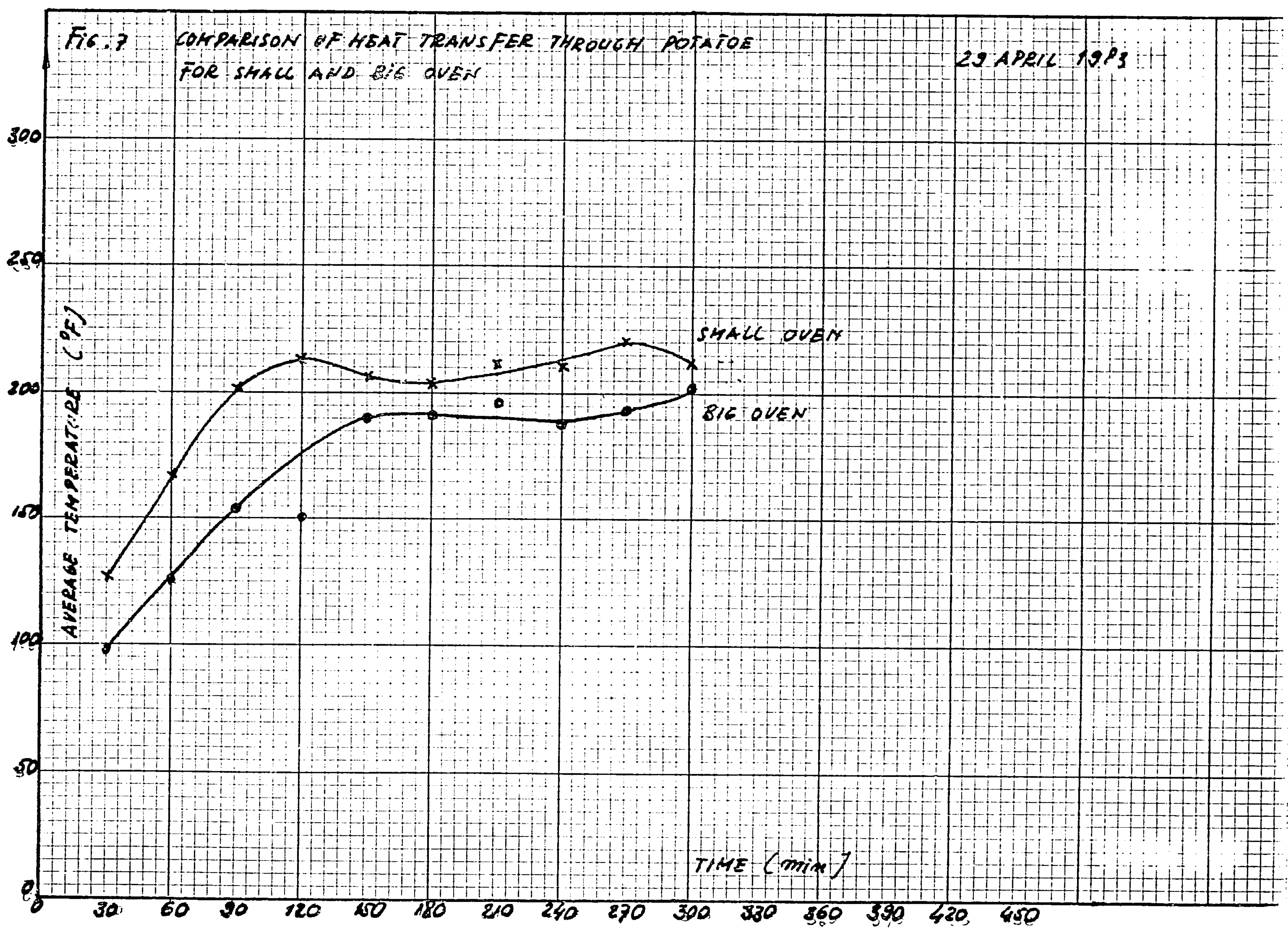

FIG. 7 COMPARISON OF HEAT TRANSFER THROUGH POTATOE FOR SMALL AND BIG OVEN

heated up faster than the oven with a reflector. In order to reduce the quantity of vapor forming, a few small holes can be drilled at the edge of the small oven in between the double glazing glasses. In the case of the small oven, the depth of the absorbing tray must be increased. The reflector should be automatic to track the direction of the sun's rays. Usually, the reflector was operated manually and if it should reflect the sun's rays most of the time, then an operator should always be around. However, in our work it was not possible as lectures were also in progress at the same period that the experiment was running.

CONCLUSION AND MODIFICATIONS

On cloudy days and in the night cooking with the solr ovens will not give any appreciable results. The small oven with which a reflector was provided did not perform as well as expected, probably because of too much condensation on the surface of the glass cover. Comparatively, it took less time for materials in the big oven to heat up than in the small oven. The tray of the small oven was quite shallow and which restricted us from choosing only a particular kind of a cooking pot.

For convenience, a cheap and appropriate tracking mechanism can be designed to provide an easy means of reflecting the sun's rays at all times. The big oven was too bulky. In order to save space, materials and human energy in moving it around, the size must be reduced.

To reduce condensation on the glass covers a few small holes can be drilled at the wooden edges through the space between the double-glazed mirror reflector and also through the space between the double glazing glass covers.