ELECTRICAL ENGINEERING

A FLOW SHOP RANK APPROACH TO GT SCHEDULING

أسلوب تفصيلي انسيابي للجدولة في تكنولوجيا المجموعات

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ملخص

لم تركز الطرق السابقة لتكنولوجيا المجموعات على صياغة المشكلة بل ركزت على قواعد العائلة و الإزاحة و التي قد تؤدي إلى حلول مختلفة حسب نوع المشكلة. هذا البحث يعرض طريقة استاتيكية نفاذية لحل مشكلة نظام الخلية للتشغيل تحت ظروف غير محدودة. و تعتمد أساسا على تحليل العائلة إلى عائلات أصغر وإنشاء شبكة توضح علاقات الإعداد بين الماكينات المكونة للخلية. و الحل مماثل لما يحدث في الخطوط الانسيابية في شكل تطبيقي بسيط. و يعتبر البحث بداية لصياغة مشكلة تكنولوجيا المجموعات في صورة انسيابية لتبسيط تحليل الخلية.

ABSTRACT

Previous group technology heuristics have not focused on the problem formulation: they have focused on family and dispatching rules which lead to different results depending on the type of the problem. The objective of this paper is to present a ***static exhaustive*** heuristic to solve such problem for unlimited job shop manufacturing cell. It is mainly based on decomposing the cell-queue into subfamilies and constructing a graph showing the setup relationships between the machine arrangement and the current partition of subfamilies. The solution is similar to that made in the flow shops in a simple applicable fashion. The heuristic is a trial to formulate the problem in an equivalent flow shop to simplify the cell assessment.

Keywords: SUBFAMILY; CELLULAR, SEQUENCE

1. INTRODUCTION

Group technology is a manufacturing philosophy based on the similarities of production and design requirements exist between parts produced in a manufacturing shop. The concept of group technology (cellular manufacturing) is to segregate a manufacturing system into cells and classifying parts into families via coding schemes and grouping techniques; for a review, see Groover [9]; Xu and Wang [19], Moiser [16], and Askin et al. [2]. A part family is a collection of parts which posses similar manufacturing characteristics. Each cell includes a number of machines which are able to process a family of parts. Cellular manufacturing provides an attractive alternative for manufacturing job shops (Burbidge [4,5], Knox [12], Black [3]), and numerous case studies of actual implementations indicate a substantial increase in efficiency (Allison and Vapor [1], Droy [6]). Benefits mentioned in the literature: lower work-in-process inventory, shorter manufacturing lead times. reducing material handling , and better quality (Greene and Sadowski [8], Suresh and Meredith [18]). The work in **GT** goes into two-class problems: first is the formation of part families and machine cells; second is the scheduling in a manufacturing cell which is the field of interest of this paper. The group scheduling [illegible] in the literature requires a two-stage procedure. The first stage sequences the jobs [illegible] subfamily while the second sequences the subfamilies in the queue of each machine cell

Vithiananthan and McRoberts [20] reported the first study in group scheduling by decomposing each part family in the queue of the cell based on setup similarities into subfamilies and treating each subfamily like a flow shop problem. Sundaram [17] proposed two *static* heuristics based on minimization of makespan to find a reasonable sequences. Mosier et al. [15] proposed two exhaustive and non-exhaustive queue selection heuristics concerned with the efficiency in the cellular manufacturing shop. Kelly et al. [11] proposed two cost oriented and exhaustive queue selection rules. Flynn [7] proposed a simple queue selection heuristic attempts to minimize the number of setups. This heuristic is based on the repetitive lots concept (Jacobs and Bragg [10]) and the ***FCFS*** dispatching rule. Mahmoodi et al..[13] have used computer simulation to test three queue selection rules in conjunction with three dispatching rules under eight experimental conditions. Mahmoodi and Dooley [14] presented *non-exhaustive* heuristics and compared them with existing exhaustive heuristics in a job shop cell environment using computer simulation.

2. ASSUMPTIONS AND RESTRICTIONS

In order to present the proposed heuristic as clearly as possible, the following assumptions have been imposed.

1. The main objective is to minimize the setup changeover and the cell makespan.
2. The second objective is to accumulate the idle time before each machine to smooth the time assignments and minimize the machine stoppage.
3. The batch consists of a considerable number of parts and the grouping problem is completed for families and cells. Also, setup requirements of the parts in the queue are defined with a complete process sheet.
4. The family in the queue of a machine cell is decomposed into a number of subfamilies according to the setup similarities; each subfamily parts have the same major setups.
5. All the jobs in each subfamily move together from machine to the next (limiting but practical in motion control). Each of the subfamilies could be treated as a flow shop problem. A machine does not switch from subfamily to another.
6. The reversible routing and cycling is not allowed. In other words, a part visits a machine once a time.
7. The number of machines in each cell is not restricted.

3. DEFINITIONS

Before explaining the procedure, the terms which will be used should be defined. These terms are restricted to the proposed procedure and may be not used in other heuristics.

-Data Sheet-A tabular form, as shown in Table 1, including all parts information about ma chines (**Mi**), tools (**Tj**), and time in seconds.

-Incidence Matrix-Two dimensional array, as shown in Table 2, indicates the machines and tools used for each part. The entry 1 indicates that a machine or a tool is used, otherwise it will be 0.

-**Part Setup Matrix (P)**-Two dimensional array, as shown in Table 3, indicates how the family parts share the machines and tools. Each entry of the matrix consists of two digits, the first indicates the machine while the second indicates the tool.

-**Subfamily Basic Part**-The queue part which requires the maximum operation characteristics in the subfamily such as time, tools, and machines. The priority is given to the number of machines and the tie is broken arbitrarily.

-**Subfamily Complement Part**-The queue part which has the nearest characteristics to the basic part. The priority is given to the number of machines and the tie is broken arbitrarily.

-**Subfamily Setup Matrix (F)**-Two dimensional array, as shown in Table 4, indicates how the subfamilies shares the machines and tools. Each entry of the matrix consists of two numbers, the first indicates the number of shared machines and the second indicates the number of shared tools. This matrix is so helpful for the purpose of finding which subfamily must visit the cell first and which subfamily will follow in order to minimize the tool changeover.

-**Machine-Subfamily Graph**-A graphical plot, as shown in Fig. 2, for the routes of subfamily parts on the machine cell.

-**Machine Relationship Matrix (M)**-Two dimensional array, as shown in Table 5, indicates the dependency relationships between the machines. In other words, it shows if a machine can start directly without waiting for feeding from other machines or it must wait for work-in-process; this depends on the operations of parts. The entry 1 indicates that the machine in column is dependent on the machine in row, otherwise an entry 0 exists.

-**Subfamily Time Cycle (C)**-The central time allocated to each subfamily. It will be used as a decision cut point. It is not an exact quantity, but it is used as a trial to equalize the time allocated to each subfamily.

-**Subfamily Time Content (FT)**-The total operation time of all parts composes each subfamily. It may be around the cycle time by a value specified by the system engineer.

-**Ready Machine List (ML)**-The list of cell machines that can start work at the current machine assignment point. This list is updated each time an assignment decision is intended. In other words, a machine is belonging to this list when all work assigned to the preceding machines is performed.

4. PROCEDURE

This section of the paper describes a new heuristic procedure for solving the problem of machine cell scheduling through an equivalent flow shop image to the **GT** cell. With reference to Fig. 1, it begins with the input of parts and cell information which involves operations, machines, tools, and times (operation and setup time). The procedure is involved in four main parts. In addition, other mechanisms are included in between such as computing, ranking, making decisions, and registering times which are clearly illustrated on the flow chart.

COMPOSING THE SUBFAMILIES

After inputting the data, the part setup matrix is prepared to determine the setup similarities between parts. The major family of parts is decomposed, based on setup similarities, into subfamilies, such that scheduling each of the subfamilies could be treated as a flow shop problem. Each subfamily begins with a basic part and followed by the complement parts. A decision cut parameter will be used, the subfamily cycle time, to close each subfamily; this to add some smoothness to the work content and the forced idle time. In other words, this minimizes the work under unpredictable conditions.

INTERACTING CELL AND SUBFAMILIES

The subfamily setup matrix is prepared to determine the setup similarities between subfamilies. Then, the machine-subfamily graph is plotted to illustrate the routes of subfamilies and the conditions of machines. Some machines can be the first host for some subfamilies and other machines must wait until the preceding operations were completed; such conditions are mainly dependent upon the first part in each subfamily in the queue. This graph determines the machine relationship matrix which, in turn, indicates how the machines restrict each others. Thus making it possible to weight and rank each machine according to the number of direct successor machines, **MRn**, and the total processing time allocated, **MRt**, given that the major family will be processed. The machine which registers the maximum number of successors is ranked one and the machine which will be assigned the minimum operation time is also ranked one. The sum of these two ranks, **Mre**, represents the equivalent rank for each machine at this point.

FINDING THE EQUIVALENT FLOW SHOP

An equivalent flow shop could be multi-inlet-outlet depending on the conditions of the processed subfamilies. The machines are sequenced by updating the ready list and using the rank obtained from the previous part. The machine in list which registers the minimum equivalent rank will be set at the top of the sequence and so on. The machines are reranked, **MR**, such that the first machine is ranked one and so on. This rank will be constant through the procedure application.

An image is considered such that the machines are arranged in a flow shop where each machine represents a station starting from the first machine which is considered the imaginary inlet and ending to the last machine which is considered the imaginary outlet. If a subfamily will not visit a machine, it is imagined to visit and leave it in an interval zero.

ASSIGNING SUBFAMILIES

Before going to assign the subfamilies in the queue, they are ranked, **FRm**, according to their routes on the machine cell. This rank will not vary in the next steps. Each subfamily rank registers the sum of ranks, **MR**, of all machines be visited minus the number of these machines, **N**; for example if a subfamily will visit the first, the second, and the third machine, it will be ranked three. Considering this rank, in the following steps, making it possible to schedule the cell as a flow shop and trying to operate all machines at the first part of time.

The queue subfamilies are ranked, **FRs**, according to the cell setup already exists for the current subfamily considering the priority for the tools. The nearest subfamily in setup to the current one is ranked one and so on; this rank is updated each assignment decision point. This to help in minimizing tool changing for each next subfamily. Also to keep the advantage of flow shop, this rank is averaged with **FRm** to get the average rank, **FRa**. Each assignment point, the subfamily of minimum **FRa** is selected. When the cell is busy (at least one machine works), the subfamilies in the queue are still registering waiting, but also some machines may register waiting. Every time an assignment is made, the waiting time for both machines and subfamily must be registered to find finally the total time required to get all subfamilies out of cell. The parts in each subfamily are sequenced at each machine according to the current setup, otherwise, the short processing time (*SPT*) rule is applied. The output of the procedure will illustrate the final time schedule.

5. A CASE PROBLEM

Table 1 illustrates the processing data for 15 parts manufactured using a cell consists of 6 machines, each of them can be set with a specified number of tools. The incidence matrix is prepared as shown in Table 2 from which the part setup matrix, Table 3, is prepared. The parts are classified into four subfamilies as shown in Table 4 which also illustrates how the subfamilies share the machines and tools to assess the priority of sequence to minimize the tools changeover between each successive subfamilies. The routes of su - families are plotted on the graph shown in Fig 2 from which Table 6 is prepared. The procedure continues with ranking the machines according to the number of direct successors and the total processing time allocated to each machine as shown in Table 6. According to the procedure, the equivalent flow line will be machines 1,2,3,4,5, and 6 respectively; this will be different for another group of parts. Begin with the minimum ranked, **MR**, machine which will be machine 1 in this case and select from the queue the minimum ranked, **FRm**, subfamily which starts with this maehine to visit the machine cell. Break the tie by the subfamily which occupies the cell in minimum time; i.e., subfamily 4. If the procedure continues, and each time the machine of minimum **MR** is selected, the subfamilies will be sequenced 4,1,3, and 2 considering the priority in sharing tools to minimize the tool changing. The parts in each subfamily is sequenced according to the current setup rule and/or the *SPT* rule.

6. CONCOLUSION

If the proposed heuristic is traced from the beginning, its effectiveness will be obvious in sub-familiarization and scheduling. It tries to mix all the advantages of minimizing the tool changeover by picking up the similarities between queue subfamilies in setup in addition to the similarities between the parts in the same subfamily, and the total shop visiting time. From the results, it is seems that the cell works as a station in a nearly balanced flow line because the subfamilies are grouped in nearly equal times. And more, the difference in setup is not significant in the sequence of all subfamilies which, in turn, regulates the tool changeover.

Most of the heuristics concerning the group technology scheduling is no longer applicble to the real large GT problems. They introduced theoretical solutions which are mainly dependent upon the cell type and the number of machines included. The GT problem is very difficult to formulate, therefore, the current heuristic is considered the first one finding an approximation to the problem formulation as those of the flow lines. The current heuristie is not limited to specific characteristics of the GT cell as in the literature. The proposed heuristic may be an integral algorithm actuating other tools to deal with the GT problem such as networks and linear programming.

TABLES

Table 1. Processing data. (M :machine: T :tool).

Part No	Opr.1		Opr.2		Opr.3		Opr.4		Opr.5		Opr.6		Opr.7		Total Time (seconds)
1	M1		M1		M3		M5		M6						340
	T1	90	T2	60	T5	40	T1	100	T1	50					
2	M2		M4		M5		M6								215
	T1	40	T1	50	T2	70	T3	55							
3	M1		M2		M4		M4		M5						316
	T2	45	T3	65	T2	100	T3	40	T2	66					
4	M3		M3		M5		M6								235
	T1	30	T4	80	T1	55	T2	70							
5	M1		M3		M4		M5		M6						302
	T3	48	T1	87	T2	67	T1	40	T2	60					
6	M1		M3		M5		M6								227
	T4	92	T2	35	T2	43	T3	57							
7	M1		M2		M3		M3		M4		M5		M6		424
	T4	47	T2	60	T3	52	T4	88	T1	102	T1	30	T1	45	
8	M1		M2		M4		M5		M6						377
	T1	92	T3	82	T3	72	T2	61	T3	70					
9	M2		M3		M4		M5								265
	T1	69	T5	58	T2	106	T1	32							
10	M3		M4		M5		M6								214
	T3	100	T1	37	T2	48	T1	29							
11	M1		M2		M3		M4		M5		M6				392
	T2	85	T3	56	T1	48	T2	62	T2	37	T2	104			
12	M1		M1		M3		M5		M6						316
	T1	59	T2	82	T5	54	T1	89	T1	32					
13	M1		M2		M4		M5								292
	T2	81	T3	51	T2	100	T2	60							
14	M1		M2		M3		M3		M4		M5		M6		433
	T4	63	T2	42	T3	56	T4	67	T1	107	T1	43	T1	5	
15	M2		M3		M4		M5		M5		M6				378
	T1	45	T5	60	T3	40	T1	82	T2	47	T3	104			

Table 2. Incidence matrix of machine-tool.

Part	M1				M2			M3					M4			M5		M6		
	T1	T2	T3	T4	T1	T2	T3	T1	T2	T3	T4	T5	T1	T2	T3	T1	T2	T1	T2	T3
1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0
2	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1
3	0	1	0	0	0	0	1	0	0	0	0	0	0	1	1	0	1	0	0	0
4	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	1	0
5	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0
6	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1
7	0	0	0	1	0	1	0	0	0	1	1	0	1	0	0	1	0	1	0	0
8	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	1
9	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0
10	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	1	0	0
11	0	1	0	0	0	0	1	1	0	0	0	0	0	1	0	0	1	0	1	0
12	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0
13	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0
14	0	0	0	1	0	1	0	0	0	1	1	0	1	0	0	1	0	1	0	0
15	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1

M 1	M 2	M 3	M 4	M 5	M 6
1	0	1	0	1	1
0	1	0	1	1	1
1	1	0	1	1	0
0	0	1	0	1	1
1	0	1	1	1	1
1	0	1	0	1	1
1	1	1	1	1	1
1	1	0	1	1	1
0	1	1	1	1	0
0	0	1	1	1	1
1	1	1	1	1	1
1	0	1	0	1	1
1	1	0	1	1	0
1	1	1	1	1	1
0	1	1	1	1	1

Table 3. Part setup matrix (P).

Part	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	20	21	31	41	40	42	31	22	31	41	45	21	42	32
2		31	20	30	22	41	42	31	32	41	20	31	41	42
3			10	31	21	40	43	31	21	44	21	44	40	32
4				33	30	32	20	21	30	32	31	10	32	31
5					40	51	40	32	40	53	41	31	51	41
6						41	32	20	31	41	40	21	40	32
7							50	41	43	60	42	40	67	51
8								30	31	52	31	42	50	43
9									30	41	22	31	41	43
10										41	31	21	43	41
11											41	44	60	51
12												21	42	32
13													40	31
14														51

Table 4. Subfamily setup matrix (F).

Subfamily	1	2	3	4
Parts	7, 14, 11	15, 8, 9, 2	5, 12, 1, 6	3. 13, 10, 4
Part Time	424,433,392	378,377,265.215	302.316,340.227	316.292,214,235
Total Time	1249	1235	1185	1057
Subfamily 1		6,4	5,8	6,11
Subfamily 2			5,6	6.6
Subfamily 3				5,7

Table 5. Machine relationship matrix (M).

Machine	1	2	3	4	5	6
1		1	1	1	1	1
2			1	1	1	1
3				1	1	1
4					1	1
5						1

Table 6. Machine ranking.

Machine	1	2	3	4	5	6
Time sec.	844	510	855	883	903	731
MRn	1	2	2	2	2	2
MRt	3	1	4	5	6	2
MRe	4	3	6	7	8	4
MR	1	2	3	4	5	6

Table 7. Ranking subfamilies according to machines.

Subfamily	1	2	3	4
N	6	6	5	6
FRm	15	15	15	15

FIGURES

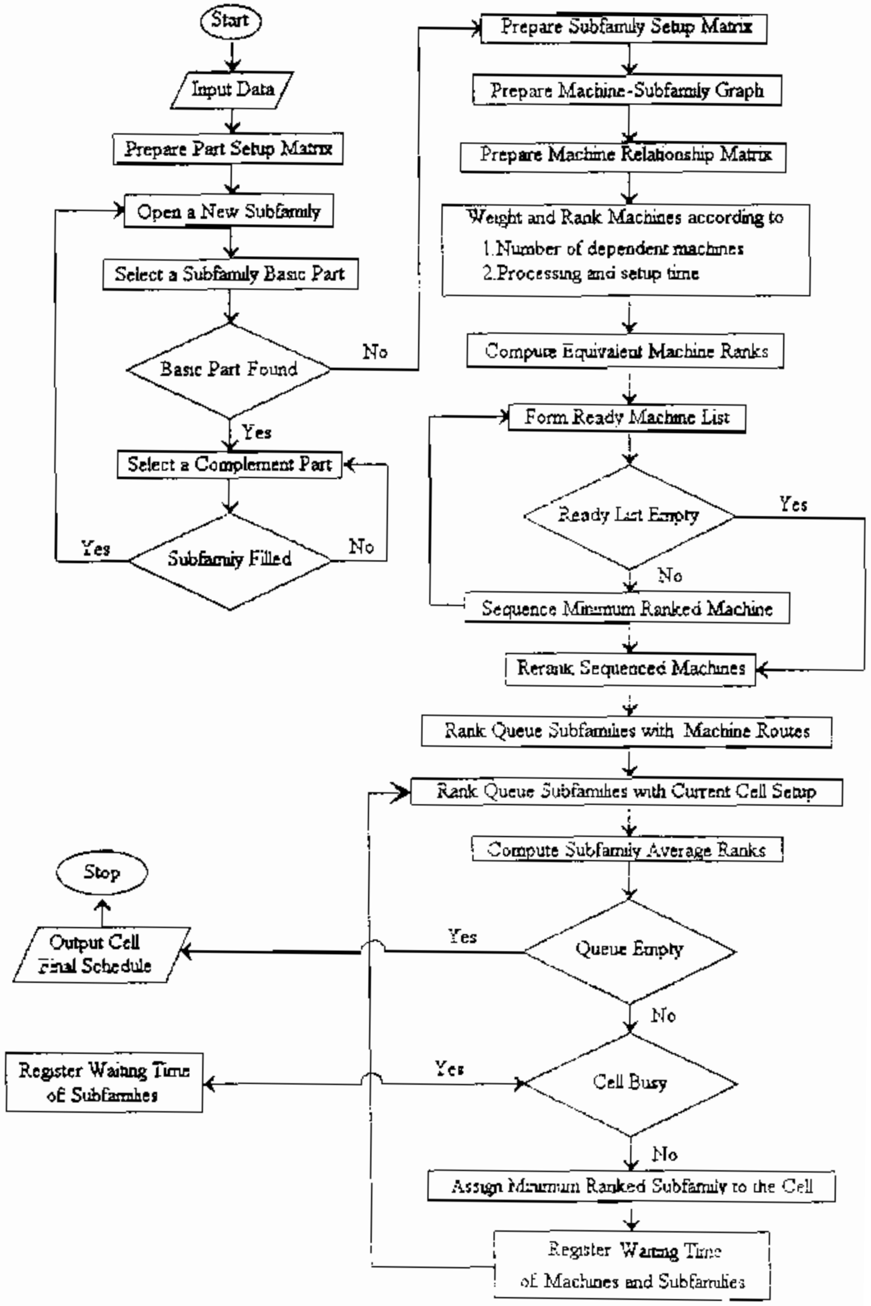

Fig. 1 The flow chart of a GT scheduling heuristic.

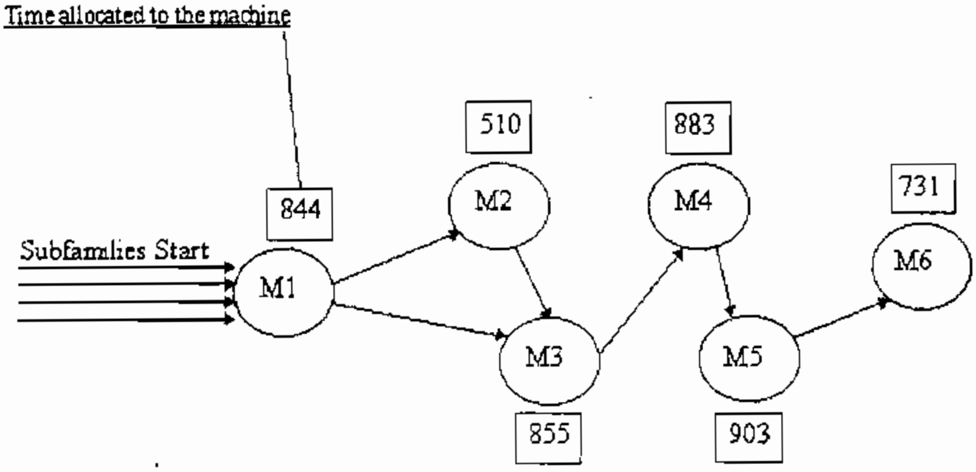

Fig. 2 Machine-Subfamily graph. (Time in seconds).

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PERFORMANCE OF A SMALL SALTLESS SOLAR POND AUGMENTED BY PLANAR MIRROR

دراسة اداء بركة شمسية مزودة بسطح مستو عاكس ،

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خلاصة : يستعرض البحث نتائج التجارب العملية لبركة شمسية صغيرة مزودة بسطح مستو عاكس . وقد أجريت التجارب بكلية الهندسة جامعة المنصورة (خط عرض 31°N). وكانت البركة عبارة عن حوض بسطح مربع (1.23m x 1.23m) وعمق مياه 0.83m ومثبت معه عاكس رأسي ارتفاعه 1.6m وعرضه 2.5m مشترك مع سطح البركة في الحافة ومتجه الى الجنوب. وقد استخدمت شرائح بلاستيكية رقيقة شفافة كعازل للسطح العلوي. وقد تم قياس الإشعاع الشمسي المقوى بالعاكس ومقارنته بالقيم المحسوبة وكانت النتائج مرضية. كما بينت النتائج أن درجة حرارة سطح البركة تصل في شهر اكتوبر الى حوالي 60°C بكفاءة تتراوح ما بين 50% الى 66% .

ABSTRACT

In the present study, the performance of a small saltless solar pond augmented by planar reflector is presented. Experiments are carried out in the Faculty of Engineering, Mansoura University, Egypt (31° N). The experimental pond has a surface of 1.23 m x 1.23 m and 0.83 m water depth. A glass mirror with 1.6 m height and 2.5 m width is supported in a common edge with the pond surface. The glass reflector is south facing and vertical in position. Plastic films are used as a top covers for the pond surface. Measurements of solar radiation, ambient temperature and water temperatures at different heights in the pond are carried out. Measured augmented solar radiation is compared with that predicted by the radiation enhancement model. The comparison has shown a good agreement between the measured and the predicted data. The temperature gradient through the storage zone of the pond ranges around 5 °C, and the upper layer of water is highly dependent on the ambient conditions. Temperatures of the plastic layers are presented during the day time, and also during the build-up period. Water temperature on the pond surface of more than 60 °C could be attained in October, with a pond efficiency ranges from about 50 % up to 66 %.

INTRODUCTION

Solar ponds are simply constructed using relatively inexpensive materials. For some applications, They will provide as much or more heat per unit collector area as conventional systems and thus they are economically attractive. Also, solar ponds provide inexpensive means for collecting and storing solar energy at temperatures below 100 °C [1]. The salt-gradient solar pond usually suffers from some major drawbacks: (i) energy harvesting must be done in a well-controlled, sometimes complicated manner, in order to preserve the salt gradient; (ii) a large salt - base solar pond may endanger the quality of the ground water basin; and (iii) large amount of salt are required [2]. However, several concepts of saltless solar ponds have been proposed in order to alleviate these drawbacks [3-6]. Membrane-stratified pond [4] and honeycomb-stratified pond [5] are examples of these concepts. Also, a saltless solar pond with a semi-transparent multilayer surface insulation system has been proposed [7-10].

A few advantages of saltless solar ponds are given by [11] as : (i) since no salt is used in these ponds, they can be made maintenance free and low cost: (ii) there is no environmental or geological hazard with saltless ponds and (iii) a large depth of lower convective zone can be maintained in a saltless pond resulting in seasonal storage, less diurnal temperature variation, and higher collection efficiency. Although solar pond has the potential to become the most economical method for the collection of solar energy in large scale applications, specially designed ponds, however, can be installed on the roofs of factories, commercial buildings or houses. In winter months the solar pond could provide large supplies of water, substantially above ambient temperatures to heat pumps. Also, another promising applications of solar pond might be to supply hot water for absorption chillers, which are used in summer air conditioning systems, or to generate process steam with the use of the absorption heat transformer by temperature boosting of heat from solar pond [11].

As the free surface of water in the pond must be horizontal, the beam radiation collected by the pond is usually limited. However, absorbed solar radiation by the pond can be enhanced with the help of a planar reflector, which must be oriented in a certain position to maximize the collected radiation either in all year-round operation or for a certain period (seasonal operation). Analysis of radiation enhancement model was presented in [12].

In the present work, the validity of the previous radiation enhancement model given by [12] for small saltless solar pond with a planar reflector and multilayer upper insulating system is investigated. Also, the operation of this pond under the Egyptian climate conditions is experimentally tested.

EXPERIMENTAL SETUP

Figure 1 shows a sectional elevation of the experimental pond. The apparatus is fabricated from a steel sheet of 2 mm thickness to form, by welding, a tank of square cross section (1.23 m x 1.23 m) and 0.83 m height. The pond sides and back, which are painted with blackboard paint from their internal sides, are insulated with 10 cm glass wool layer from the outside. The upper surface of the pond is covered with a transparent cover which consists of six polyethylene layers. The transparent layers, which have the same dimensions as the pond surface, are supported in a wooden frame such that, the space between two adjacent layers is kept at 0.01 m as shown in Fig. 2. The south faced reflector, which is mounted by two side supports allowing a change of the degree of inclination of the reflector with respect to the pond surface is 1.6 m height and 2.5 m width. The reflector is vertically supported in common edge with the pond surface and its reflectivity is 0.75.

In order to measure the temperature gradient through the pond, nine Copper - Constantan thermocouples are vertically installed along the pond center. Also, the temperatures of the cover layers are recorded by six thermocouples. Solar radiation intensity, with and without enhancement, on the pond surface and the ambient temperature are also recorded during the experimental work. The experimental setup is prepared and located on the roof of the Combustion Laboratory, Faculty of Engineering, El-Mansoura University at 31° N latitude. Temperatures and radiation data are recorded each hour during the day time, and the mean pond temperature is calculated by using the following equation [13] :

$$T_p = \left[\sum_{i=1}^{9} (T_i + T_{i+1})\, \Delta L_i \right] / 2\, L_p \qquad (1)$$

Where, L_p is the pond depth and

ΔL_i is the distance between two adjacent thermocouples located in the central part of the pond.

RESULTS AND DISCUSSION

The short term experiments with the small saltless solar pond in no load condition and enhanced solar radiation collection took place during October 1996. The performance results are described here. Figure 3.a, 3.b show typical solar radiation data. obtained over two different days with moderate solar radiation intensity. Results of diffused. horizontal, and enhanced solar radiation (calculated and measured) are presented in the two figures. A reasonable agreement between the calculated values of the enhanced radiation [12] and that measured can be observed. It is clear that radiation of about 600 W/m^2 can be enhanced to a value of about 1100 W/m^2 (Fig. 3). As expected. the reflector position and the tilt angle allows the maximum values of enhanced radiation to occur during the period of higher solar radiation (10 - 13 hours) as shown in figures. The good agreement between theory and experiment proves that the previous radiation enhancement model can be applied at different locations and different seasonal operation of the system.

Experimental time trace of nine temperatures, that recorded by thermocouples vertically installed in the pond. are given in Fig. 4, for one day of system operation. As the pond functions as a collection and storage system, the temperature of different layers increases continuously during the day time. However, the rate of temperature rise of the upper water layer is seen to be highly affected by the solar radiation intensity. Therefore, its has the highest temperature of the pond. In the same figure. the calculated values of mean pond temperature is given. Figures 5.a., 5.b show the temperature-time curves of the six layers of the upper insulation system of the pond for two different days of operation. Also, the ambient temperature and the water surface temperature are presented in these figures. It can be observed that. cover layers experience a peak occurs in temperature at noon . The. temperature drop that follows each peak occurs with a rate following the solar radiation as expected. The upper layer of the water in the pond has a temperature curve which may have a peak value at noon time. as shown in Fig. , beyond this peak the temperature is reduced. Apparently, the storage capacity of this layer is lower than that of the other layers inside the pond.

Daily temperature variation of the pond layers and the mean pond temperature during the build-up period (1/10-24/10/96) are given in Fig. 6. The temperatures shown in the figure are those corresponding to the values measured at 12 noun every day. It can be observed that, the temperature difference between the bottom layer and that adjacent to the upper layer is nearly the same for all days of the build-up period. However, the difference in temperature between the upper layer and the adjacent one is seen to be higher than that between any other two layers. This may emphasize that, the upper layer is highly affected by the ambient conditions (solar radiation and ambient temperature). On the other hand, the inside layers are more stable and can be applied as the storage zone of the pond. The vertical temperature gradient along this zone is about 4-6°C. Figure 7 shows the recorded temperatures at 12 noon each day of the build-up period for the six cover layers with the ambient temperature and pond surface temperature. It can be noticed that, the temperature of the pond surface and the cover system follow that of the ambient which changes during this period. From Figure 6, it can be observed that, the pond temperature reaches a maximum value, at the end of the build-up period. The mean value of this maximum temperature is higher than the mean ambient temperature by more than 30°C.

The hourly efficiency of the solar pond is given by [11] as :

$$\eta = c_p \rho \ L \ \Delta T / H \qquad (2)$$

Where c_p is the heat capacity, p is the density of water, L is a water depth, ΔT is the water temperature rise during one hour of operation and H is the incident total solar radiation in this hour.

The pond hourly efficiency is calculated over two days of operation and presented here in Fig. 8 . As expected, the pond efficiency at lower temperatures is high and gradually decreases as the pond temperature increases. This indicates the increase in losses to the surrounding with the increase in pond water temperature. However, if heat is extracted during the day time, as in flat plate solar collector, the average pond temperature, and therefore thermal losses, will be reduced. Thus, a higher values of average pond efficiency is expected when the pond is working in load condition, and a large fraction of the total available solar energy can be utilized.

CONCLUSION

A small, freshwater solar pond augmented by a planar reflector is constructed and experimentally tested outdoor. Results are presented for the pond warm-up with no load condition. Measurements have shown that the mean pond temperature, in October, is 30 °C higher than that of ambient temperature. Also, the hourly efficiency of the pond is calculated and found to be highly dependent on the pond temperature. The agreement between the calculated and measured values of enhanced solar radiation is reasonable, and thus, the theoretical model of the previous work [12] can be applied for other locations and seasons. The fabrication of small pond is simple and cheap when it operates as a collection and storage unit in the same time. Finally, it should be recognized that further experimental work is required for long term performance of the pond to evaluate the seasonal variation of its performance.

NOMENCLATURE

C	heat capacaity
H	pond height, incident solar radiation

L	pond depth
T	temperature
Δ	difference
η	efficiency
ρ	density

Subscripts

i	thermocouple number
p	pond

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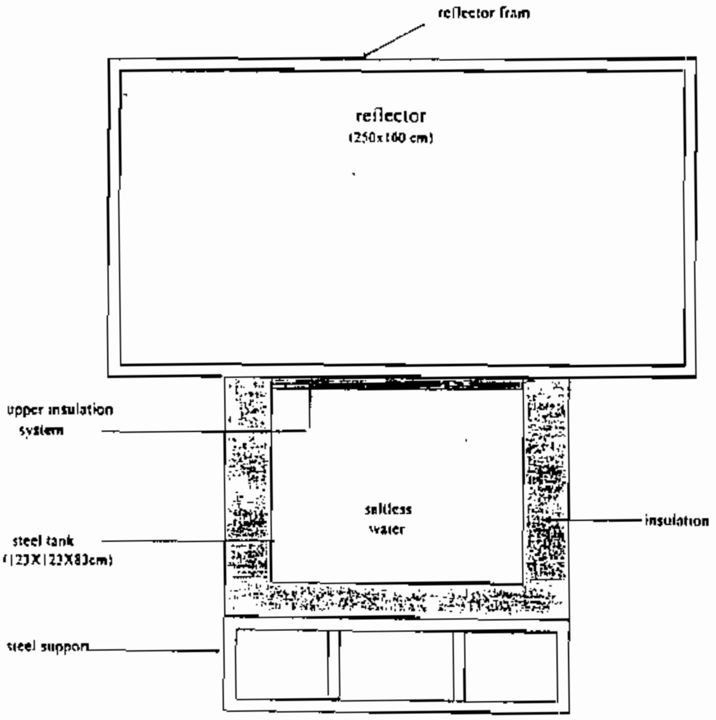


Fig.1 Sectional view of the experimental pond

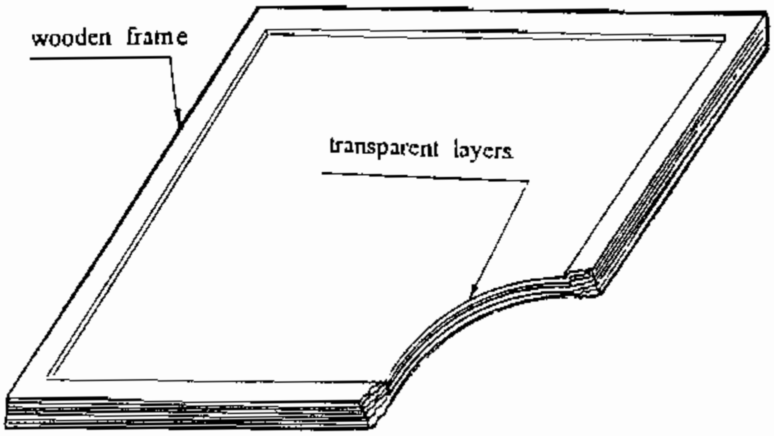
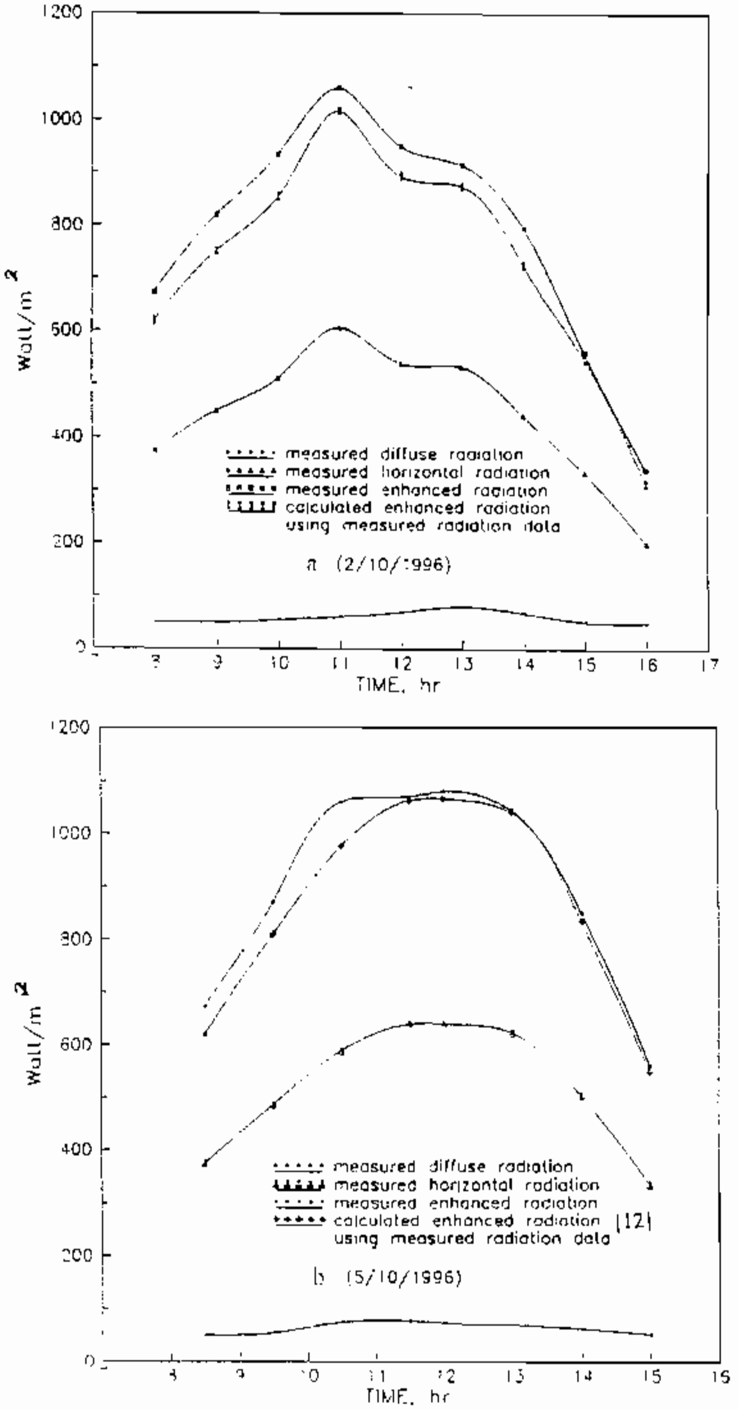


Fig. 2 The upper insulation system of the pond



. 3 Comparison between measured and calculated values of different radiation types

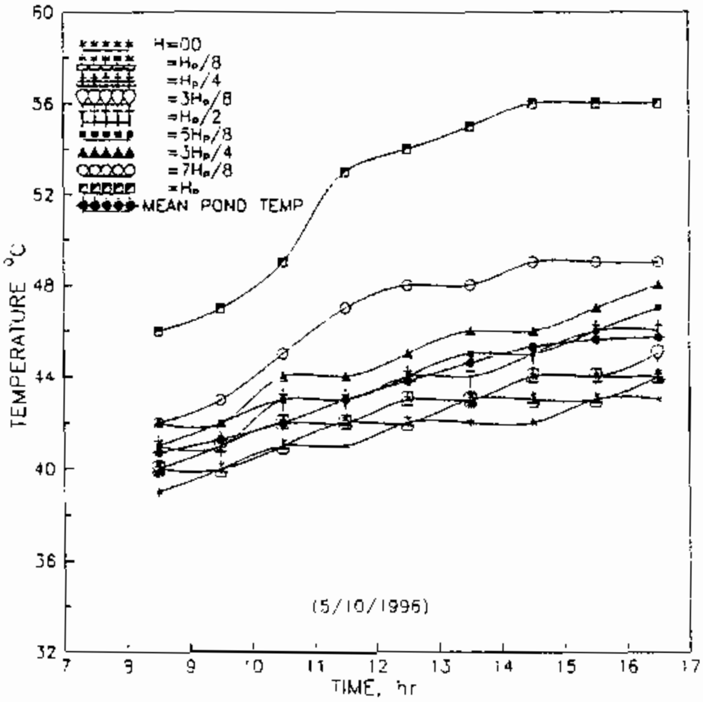


Fig.4 Pond temperature at different heights

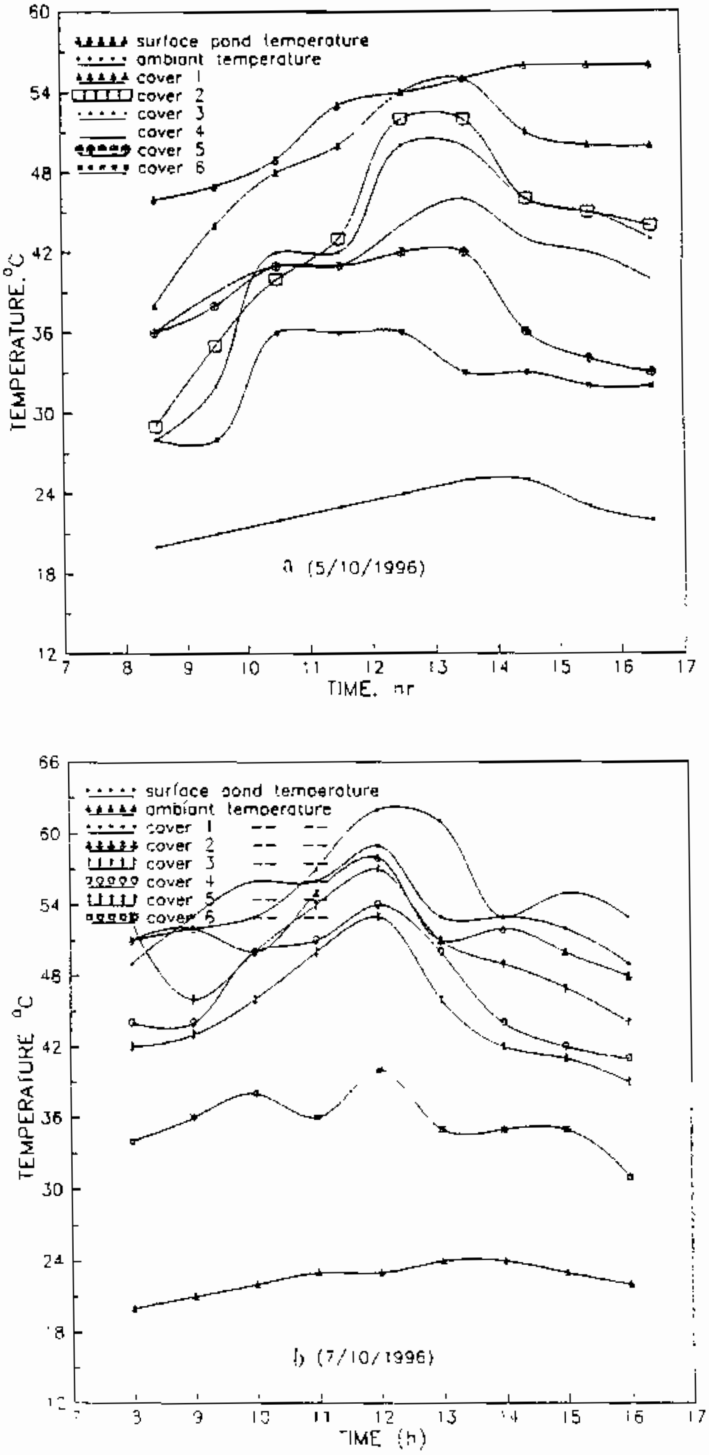


Fig. 5 The temperature - time curves of the six cover layers

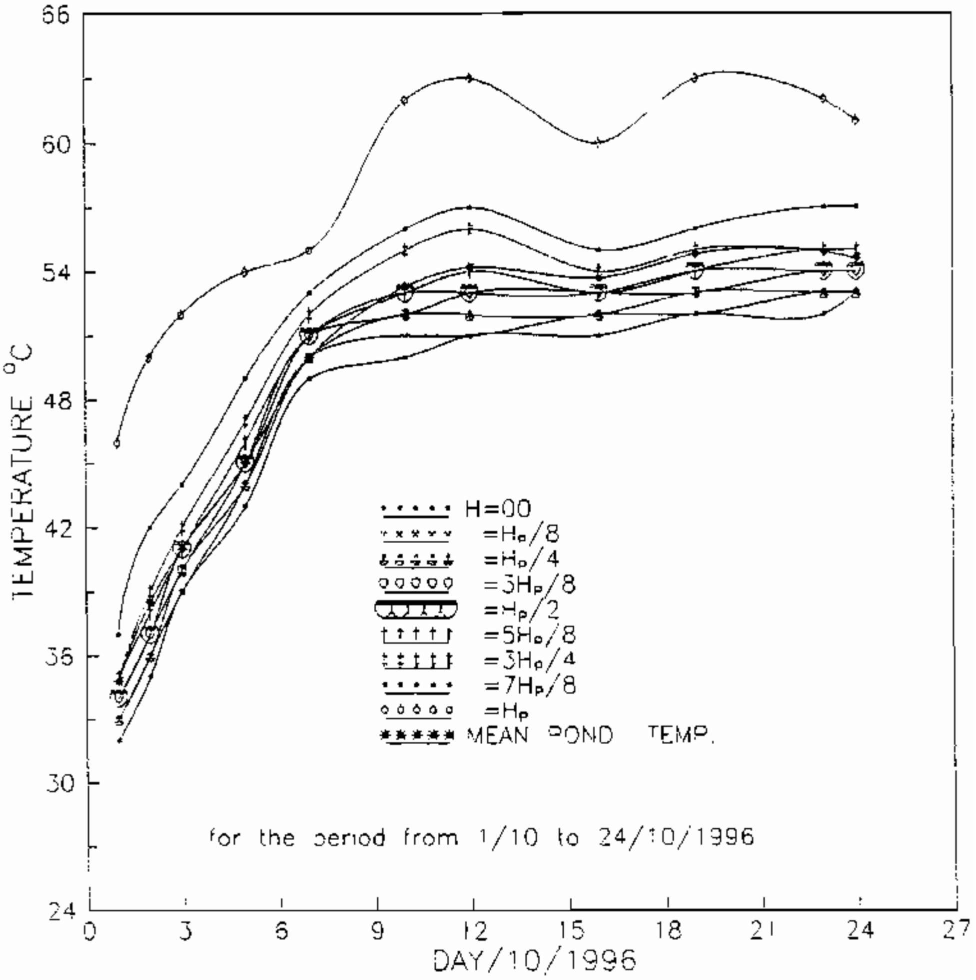


Fig.6 Pond temperature during the build-up period at different heights

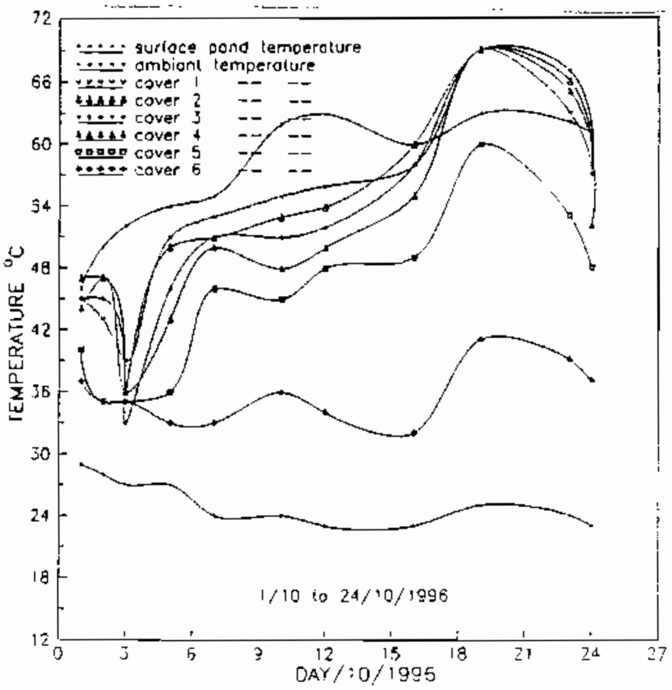


Fig 7 Temperatures of upper covers during the build-up period

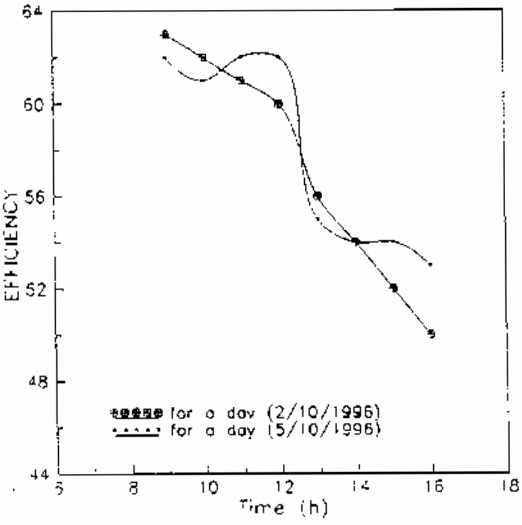


Fig 8 Overall thermal efficiency of the system