1. INTRODUCTION, OBJECT AND SCOPE OF INVESTIGATION

1.1 Introduction

Renewable energy sources have assumed importance after the oil crisis of 1973. Eversince, rapid technological developments have taken place to exploit solar energy, wind energy, biomass, etc. to meet the growing energy needs of the world. This can be seen from the recent commercial developments in the field of solar energy such as solar water and air heating systems, solar desalination, solar thermal power generation plants upto 10-30 MW level, solar refrigeration and air conditioning, etc. While most of the applications are in the industrial and commercial sectors, residential sector is also not lagging behind, especially in countries with cold climates. Distinct from thermal applications of solar energy cited above is the direct conversion of solar radiation to electricity employing photo-voltaic route.

Relevance of solar energy to our country cannot be overemphasized. Some of the important aspects are:

a) Being renewable, it is an inexhaustible source of energy. Its availability for 8-12 hours per day is not a severe constraint as cost effective energy storage [thermal, electric, hydro, etc.]

are being developed. It can be seen, at the moment, as a good supplement to the existing sources of fossil fuels [coal, oil, etc.]. It saves lots of foreign exchange by reducing oil imports.

b) Being non-polluting, it provides clean energy and saves damage being done by the fossil fuels to man and its enviorment. As an example for every 100 kW produced by renewable energy source, 0.5 kg of atmospheric pollutants are prevented.

c) Being available throughout the country [though at different intensities], it provides decentralised source of energy.

It is estimated that all renewables can meet 20-30 % of the total energy requirement of our country.

1.1.1 Solar Collectors

Common to all solar thermal applications is the solar energy collector, which absorbs the radiation, converts it to thermal energy for direct use or other applications cited above. It is worthwhile to describe briefly solar collector as its design and flow characterstics are to be investigated in the present study.

Fig. 1.1 shows different collector geometries. Any collector, depending upon the design, will contain several tubes, normally 5 to 12, except for concentrating collector which has only one tube at

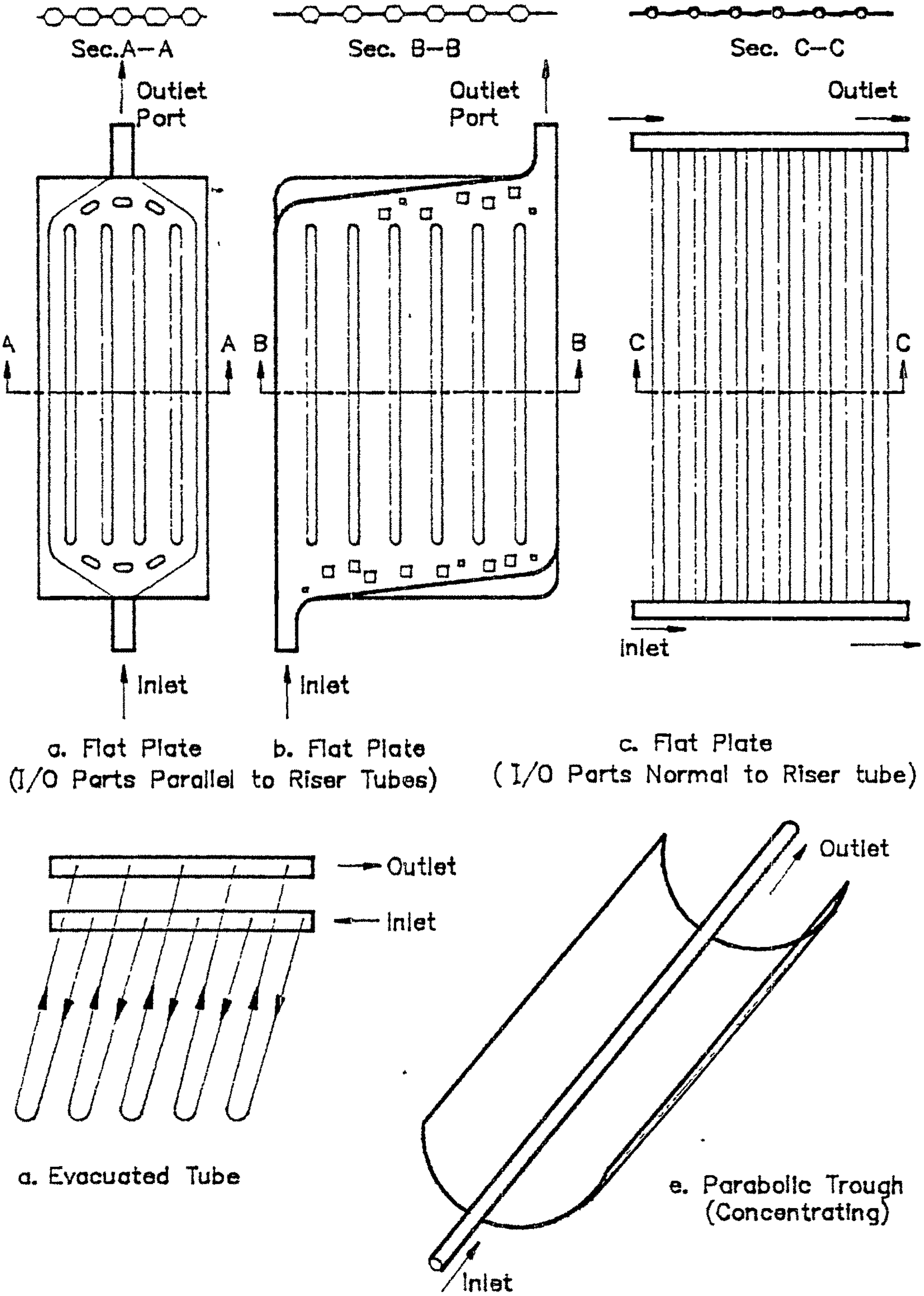


Fig. 1.1 Solar Collector Geometries

the focal line.

The geometry of flat plate collectors [Fig. 1.1(a)-(c)] is briefly discussed-to understand the flow configuration.

In Figs. 1.1(a) and 1.1(b), there are several riser tubes in parallel which meets the collector manifold at either ends. Inlet/outlet ports are provided parallel to the riser tubes. In case of Fig. 1.1(c), the inlet/outlet ports are co-axial to collector manifold (in fact, extended portion of the manifold).

A further difference between collectors of Fig.1.1(a) and (b), and that of Fig.1.1(c) is in the way working fluid is distributed. In the former, cold fluid enters from the inlet port and exits from the outlet one. In the latter, the cold fluid enters the riser tubes and the balance leaves the outlet port (bottom right), when more than one such collector are connected in parallel.

In the present work, the flow distribution in an array of flat plate solar collectors used for solar water heating is studied employing collector shown in Fig . 1.1(c). The results of this work, however, can be used for other types. For example, evacuated tube collector of Fig. 1.1(d) and solar concentrator of Fig. 1.1(e). Furthermore, there are many other conventional applications such as parallel pipe network in chemical reactors, nuclear plant, water distribution network in buildings, etc.

Therefore, the outcome of the present investigation has a wider applications in several types of solar collectors and parallel pipe network in conventional applications in industries.

1.1.2 Solar Water Heating

Solar water heating with flat plate solar collector array to provide hot water at 60°-90° C for industrial applications is gaining acceptance due to favourable economics and initial technology resistance being overcome. The collector area involved in such applictaions runs to hundreds of square meters to cater to high daily energy requirements. Recent developments indicate that many manufacturers are resorting to use of internal manifolded collector and forming an array of these collectors in parallel. This arrangement has two main advantages :

(1) Elimination of external insulated manifold, thereby reducing significantly installation cost and also heat losses.

(2) Reduction of collector array pressure drop. This reduces pump size and consequently parasitic energy requirement. Reduction in collector array pressure drop is also significant since the ratio of pressure drop for collectors purely in series to collector purely in parallel is cubic of number of tubes, the number of tubes being identical in both the cases [Kutscher (1982)].

Use of several collectors in parallel, however, cause flow maldistribution (for improper collector geometry) resulting in deterioration of collector thermal efficiency. This was observed by Dunkle and Davey (1970) and Lydon (1979). Dunkle had observed temperature differentials of 14° - 22° C for 12-module collector array in parallel. Lydon had observed similar behaviour. For 12-module array with total collector flow of 0.49 ls^{-1}, the temperature differential was 30° C and for 18-module array and total flow of 0.56 ls^{-1}, it was 45° C.

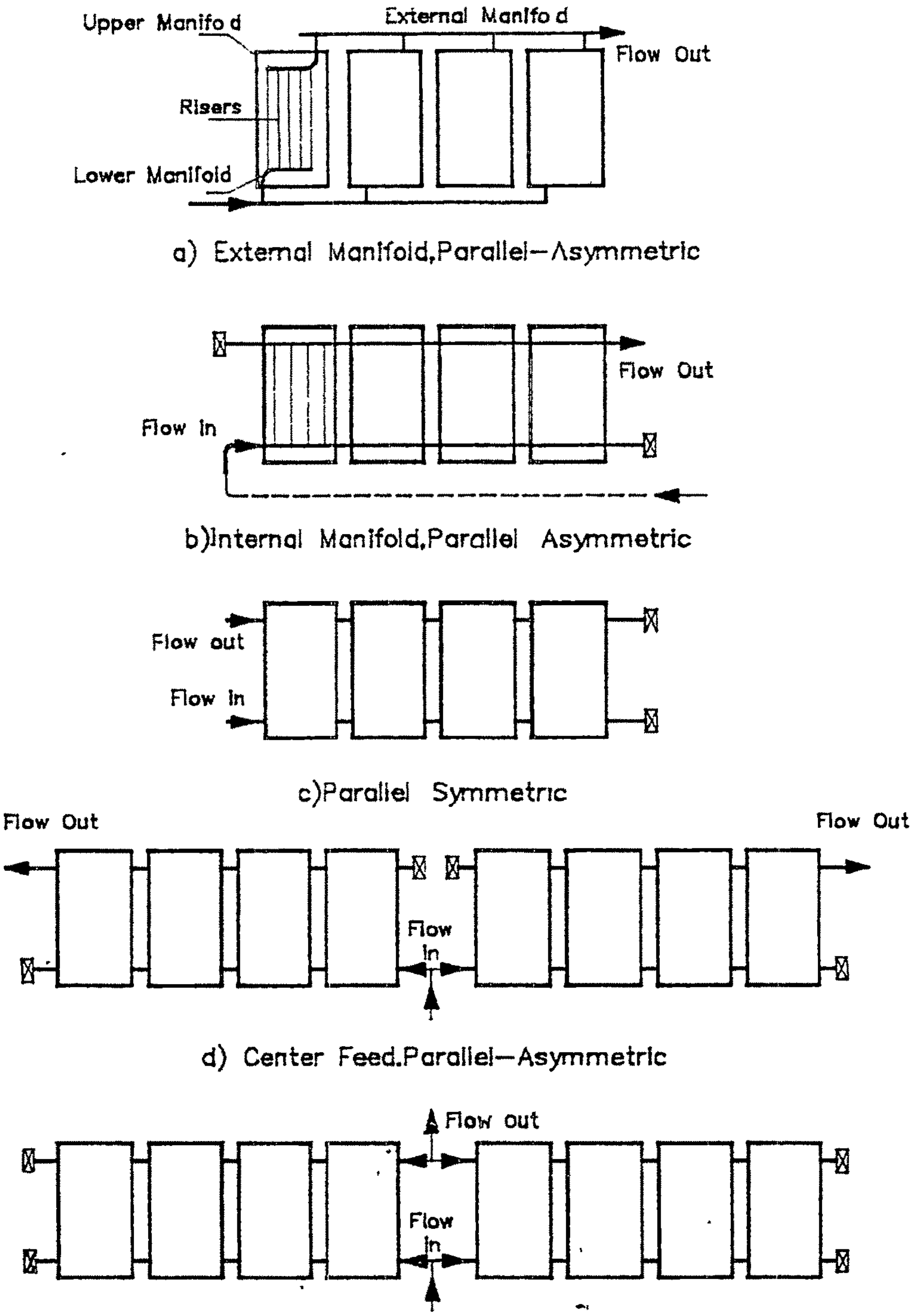
It is obvious that collector array efficiency will be significantly lower than that obtainable with uniform flow. Lydon's (1979) experimental results indicate about 10 % reduction in collector array efficiency for the above 18-module unbalanced array. Theoretical study by Chiou (1982) indicated 2-20 % reduction depending upon flow distribution pattern.

It is necessary to define manifold and array flow configuration before proceeding to the next chapter for better understanding of the problem. For solar collectors having ports (inlet/outlet) parallel to the risers [Fig. 1.1(a) & 1.1(b)] an external manifold is required for an array of collectors in parallel besides the ones existing in the collector manifold [Fig. 1.2(a)]. On the other hand, for those collectors having side ports co-axial with the collector manifold (in fact integral part) (Fig.1.1(c)), the collector manifolds become the array manifold [Fig.1.2(b)-(c)] when they are connected in parallel. The later is, therefore, aptly called internal-manifolded collector.

Fig. 1.2 shows different array flow configuration. Two basic patterns are observed, namely Symmetric or U-manifold and Asymmetric or Z-manifold. For asymmetric mode, cold water enters the lower manifold at one end and exits from the upper manifold at the other end of the array [Fig. 1.2(b)]. In symmetric mode, entry of cold water and exit of hot water are at the same side of array [Fig. 1.2(c)].

It can also be observed that symmetric array feeding has an advantage of using less insulated pipings compared to asymmetric one [see Fig.1.2(e) and 1.2(d)]. However, it is a general practise to prefer asymmetric feeding as this is believed to give better flow distribution. Further, other thumb rules specify that manifold should be large enough so that the major pressure drop is due to the risers. Such thumb rules are based on certain observations while valid for particular condition need not be applicable for all situations. This can be illustrated by normal plumbing practises for asymmetric feeding or commonly called 'reverse return' piping (see Fig.1.2.(b) shown by dotted lines), while Collier (1976) and Pigford (1983) observed otherwise. This is due to the fact that system network size and flow rates encountered are quite different, while both observations are correct individually.

A designer, on the other hand, requires much more than these thumb rules to arrive at a proper design and perform optimisation.



e) Center Feed,Parallel–Symmetric

Fig.1.2 Array Flow Configurations in Solar Collector Array With Collector in Parallel.

Also most of parallel pipe network studies, Collier (1976) and Pigford(1983), were done for turbulent range, and for a few risers, say 4-10 except in the theoretical analysis made by Pigford (1983) for risers upto 100 numbers. On the other hand, solar collector array involves laminar flow in the risers and turbulent in certain sections of the manifold, while number of parallel tubes range from 10-12 for a single collector to 100-120 for 10 collector modules in parallel. An exception to this is the study of McPhedran et.al (1983) on flow distribution in evacuated tube collectors.

1.2 Object and Scope of the Study

The present work, therefore, addresses to :

1. Formulation of mathematical model for internal manifolded solar collector array, both for symmetric and asymmetric feeding.

2. Experimental verification of the mathematical model by electro-chemical technique.

3. Study the effect of collector parameters (geometry) and system parameters (flow and no. of collectors in parallel) on the flow distribution.

4. Correlate the flow distribution to collector array efficiency.

5. Suggest method of array balancing by suitable design of collector geometry for 10-15 module in parallel (i.e. without any external balancing methods).

The reason for selecting electro-chemical technique is that flow rate measurements in the risers can be done more accurately with good repeatability. On the other hand, pressure change technique requires very sensitive pressure measuring instrument as the flow rate in the riser is laminar (Re = 250-500).

The results of the present study will be useful in the following ways :

(a) The experimentally verified mathematical model shall enable a solar designer to design a collector layout. The number of collectors in parallel can be chosen given collector geometry and flow rate to achieve a very low flow maldistribution correlated to the collector array efficiency. This can be extended for parallel arrays further in parallel or in series. This allows the designer to achieve collector array thermal efficiency nearly the same as that of single collector module at design point.

(b) Keeping as many collectors as possible in parallel within the constraints of flow maldistribution and site lay out significantly reduces collector array pressure drop. This consequently decreases the pumping power requirement (parasitic losses) and size of the pump. This way the initial cost and running cost of pump are reduced.

(c) The same model can be extended to other types of collectors, e.g. evacuated tube [Fig.1.1(d)] and concentrating [Fig. 1.1 (e)] collectors. These collectors have common configurations when connected in series and parallel.