Spectrum

Improvements in solar collector technology

Three new CSIRO developments offer significant improvements in the heat-collecting efficiency of flat-plate solar collectors.

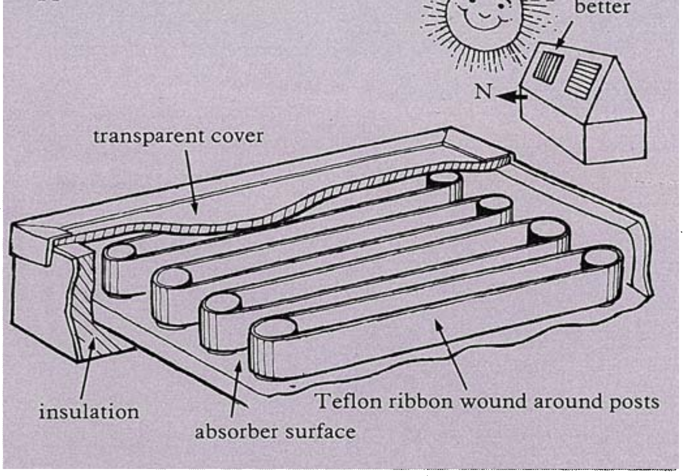
They are results of work directed mainly towards designing solar collectors for industrial use, where higher temperatures (up to 150°C) are required than those encountered in normal domestic solar water-heaters (around 70°C). Funds from the National Energy Research, Development and Demonstration Council (NERDDC) are supporting this research, which includes studies of evacuated tube collectors and concentrating devices, as well as flat-plate absorbers.

Convection suppression

As the operating temperature of a collector rises, heat losses become more pronounced. One of the significant heat-loss mechanisms is convection, in which circulating air cells take heat from the hot absorber surface to the cooler transparent front cover of the collector.

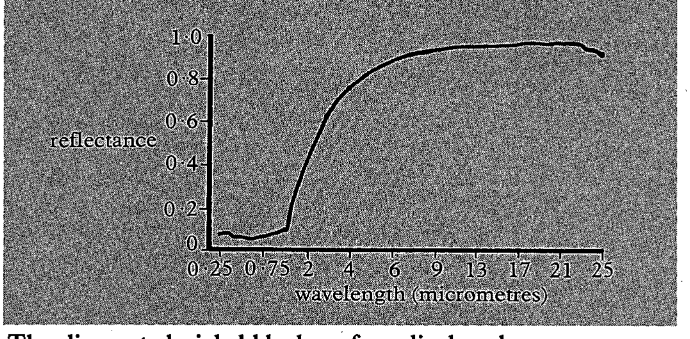
The first of the new developments stems from an improved understanding of how heat is lost by convection. Against intuition (and established practice), Dr Jeffery Symons and Mr Malcolm Peck, of the Division of Energy Technology at Highett, Vic., have found that dividing the space inside a flat-plate collector into channels running up and down suppresses convection much more effectively than breaking it up into channels running crossways.

Channels — one way to suppress convection



Winding transparent Teflon ribbon around a series of posts is a simple way of dividing into channels the space between an absorber and its transparent cover. The channels suppress convection, but for best performance they should run up and down, not crossways.

The selective surface performs well on galvanized iron



The dip-coated nickel-black surface displays low reflectance at short wavelengths and high reflectance at long wavelengths—the hallmark of a good selective surface.

This fact forms the basis of a convection-suppressing device they have invented. Their idea is to wind thin (13 μm) transparent Teflon ribbon around posts so as to create channels that cut down air circulation (see the diagram).

Many patents already exist for honeycomb structures that do a similar job. Channels, suppressing convection currents in one direction only, may not work as well as small-celled arrangements, but they are considerably cheaper to make.

Dr Symons and Mr Peck have studied a number of designs for convection-suppression devices, including some that employed channels oriented across the collector. Although convection is a complex phenomenon, theory suggested to them that it should be countered more strongly if the channels were aligned in an up-and-down configuration.

Experiment confirmed this theoretical notion. The absorber surface of a flat-plate collector, with a cover 40 mm in front of it, can get no hotter than 10°C above the temperature of the cover (20°C) before convective heat losses set in, if crossways slats are used.

In contrast, when an up-and-down arrangement is employed, the absorber can be 57°C hotter than the window before convection begins. Using the convection-suppression ribbon, the typical operating temperature of a collector can be raised significantly.

The Division has applied for a patent covering the idea of channels running up and down, and it hopes manufacturers will show interest in using, under licence, this method of improving collector performance.

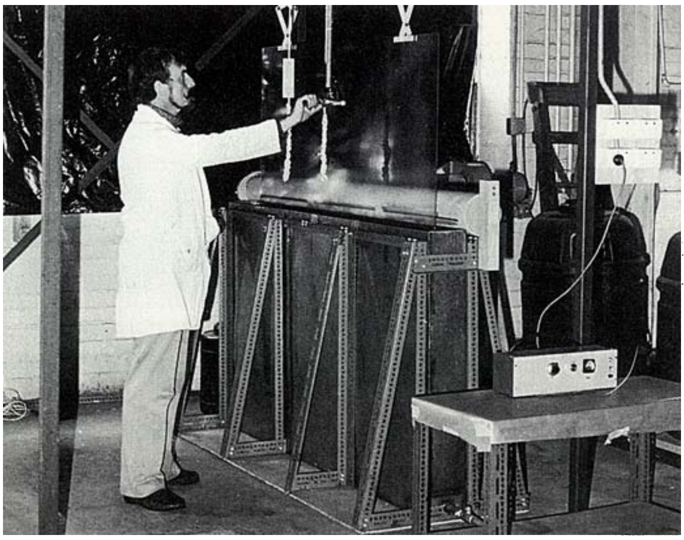
Selective surface

Another development allows efficient collectors to be made from galvanized iron. It provides a selective absorber surface on this low-cost material, which can be applied with a chemical dip instead of expensive electroplating.

Most solar collectors use black paint as the absorber surface. For the higher efficiency needed for higher-temperature heating, special selective surfaces are used (for an explanation of how they work, see *Ecos* 17). The selective surface is commonly applied on a copper base.

Dr Keith Cathro of the Division of Mineral Chemistry has found that a durable nickel-black surface can be obtained on any zinc-coated material, including galvanized iron, by purely chemical means. The cleaned absorber panel is simply dipped into a warm solution of nickel sulfate and ammonium thiocyanate for about 30 seconds.

Dr Cathro has also adapted the process to work on Zincalume (similar to galvanized iron, except it has



Putting an anti-reflection coating on a collector's glass cover.

an aluminium–zinc alloy coating), and with zincated aluminium. All these materials conduct heat less effectively than the traditionally used copper, but they are considerably cheaper.

Solar absorptance values of 0·93 (a perfect absorber would have a figure of 1) can be obtained on galvanized iron using the technique. A corresponding emittance figure of 0·13 shows that the material is a reasonably good selective surface (a zero figure would mean no heat loss by radiation). Similar values have been recorded for the other base layers used.

Several manufacturers of solar collectors are investigating the feasibility of using the process in their factories; before long we may see in the market-place practical results of Dr Cathro's research.

Reduced reflection

Dr Cathro is also involved in another research program designed to improve collector efficiency; this time he and his colleagues are aiming at reducing the amount of sunlight lost by reflection from the collector's cover.

Most collectors are fitted with one or more transparent cover plates to minimize heat losses from inside the unit. The glass and plastic covers let through 80–92% of the sunlight falling on them. The remainder is lost through absorption in the cover and reflection from it.

Not much can be done about loss by absorption, since it is a function of the material's chemical composition, although the use of imported low-iron glass provides some improvement over standard glass. But measures can certainly be taken to reduce losses caused by reflection of sunlight from the cover plate.

Low-reflection films have been applied to optical equipment for many years. However, it is out of the question to apply the costly coating techniques used with lenses — vacuum evaporation of a layer of magnesium fluoride, or multi-layers of metallic oxides — to the large areas of collector cover. Dr Keith Cathro and his colleagues have been looking at cheaper ways of doing the job.

They have developed a simple dipping process for applying two sorts of low-reflectance films to the cover plates of solar collectors. They have successfully coated glass, acrylic, and polycarbonate plastics.

The special coatings — one silica, the other polytetrafluoroethylene (PTFE or 'Teflon') — enable more sunlight to reach the blackened absorber surface and promise to yield significant economies in industrial solar applications where higher temperatures are sought.

The total area that an array of collector panels needs for a given application could fall substantially if the cover plates are coated with such films. For instance, a coating that could reduce reflectance from 7·5% to 2·5%, for a typical single-glazed collector with an operating efficiency of 30%, could reduce the collector area required for a given job by 13%; for a double-glazed unit, an area 20% smaller would suffice.

The refractive index of the coating chemical determines how effective it will be in reducing reflection. The ideal figure for obtaining minimum reflectance with normal glass is 1·23.

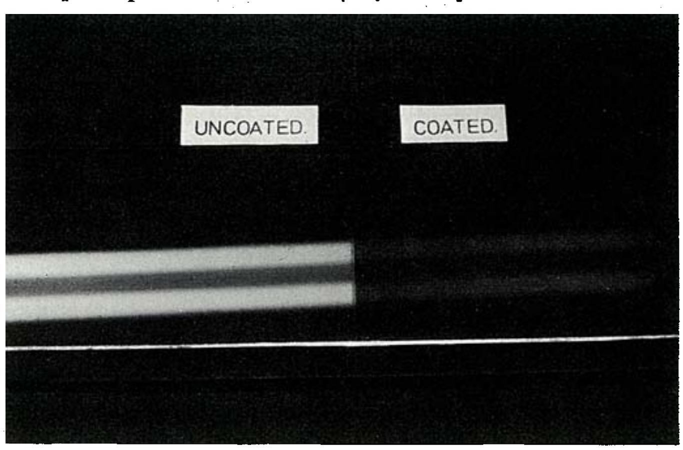
But, unfortunately, no known substance (at least, none that is sufficiently transparent and could be used as a coating) has this refractive index. Several fluorides, including PTFE, have an index of about 1·34; silica, which is cheap and produces negligible absorption losses over the solar spectrum, has a figure of 1·45.

However, the refractive index of a porous material is lower than that of the solid material, providing the pores are small compared with the wavelength of light. Thus, if a porous silica film can be applied, this might be a solution to the problem.

Dr Cathro's team found that dipping the cover plate in a colloidal silica bath and withdrawing it vertically at a controlled speed turned out to be the best way to apply a silica coating of the right refractive index. Tiny, electrically charged silica particles (about 10 nm across) are dispersed in ethanol in the bath. A thin, porous film remains on the plate's surface after the solvent has evaporated.

With this method, the team obtained reproducible results of around 2% reflectance for silica coated on floatglass, several low-iron glasses, and acrylic and polycarbonate plastics. The best films had a refractive index of 1·265, close to the optimum 1·23. The job takes just 3 minutes. Its only shortcoming is that the coated glass sheet must be baked at 450–500°C to ensure adequate adhesion.

The team exposed 0·1-m^2 glass sheets coated by the dip method outside



The coating considerably reduces reflection from the glass.

the Port Melbourne laboratory for more than a year.

A small increase in reflectance, from about 2% to about 2·5%, occurred rapidly and occasional irregular increases followed, typically during autumn, to 3 or even 4%. As the lower reflectance is restored by washing, and hence by rain, these periods of high reflectance were usually quite brief. Washing with hot water, or with water and ethanol, restored the coatings to their initial reflectance.

It seems that the porous films adsorbed atmospheric pollutants, and these have a higher refractive index than the air they displace in the pores.

In the laboratory, the team tested the efficiency of a number of coated glass and plastic plates on a collector test rig and have confirmed the 7–8% gains expected in collector efficiency.

Dr Cathro is continuing with work on PTFE films using the dip method. So far these don't measure up to the silica films. The chemical does not adhere satisfactorily unless the plate is roughened, and withdrawal rates are slower.

Formation of nickel-black selective surfaces by a conversion coating process. K. J. Cathro. *Solar Energy Materials*, 1981, 5, 317–335.

'Better surfaces for solar collectors.' *Ecos* No. 17, 1978, 17–21.

Durability of porous silica antireflection coatings for solar collector cover plates. K. J. Cathro, D. C. Constable, and T. Solaga. *Solar Energy*, 1982, 27(6) (in press).

'Convection Suppression.' J. G. Symons and M. K. Peck. Australian Patent Application No. PF0660/81, 1981.