Outlook

Better surfaces for solar collectors

The prime difficulty in harnessing solar energy is that its source is 150 million kilometres away. Using a flat-plate solar collector to collect the sun's heat is like trying to heat water with a camp-fire when the billy is sitting next to you a comfortable distance from the fire. There's no doubt the water will get warm, just as you do, but there's little chance of it boiling. That's one way of looking at the problem of designing more-efficient solar collectors.

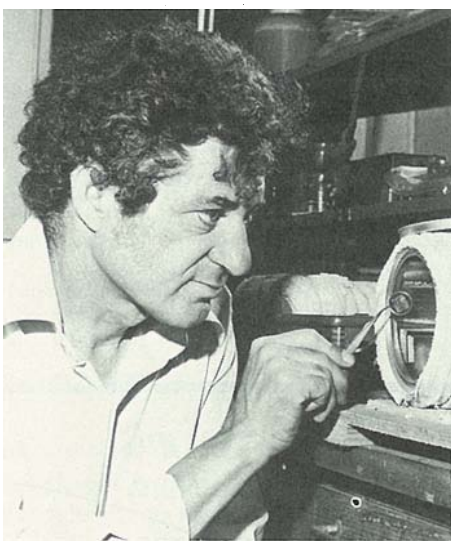
In technical terms, the 'energy density' in both cases is pretty low compared with the other energy forms engineers normally deal with. Not that we'd want it any other way. The sun is comfortably hot (give or take a bit) and that's the way we like it. Indeed, that's the reason the earth is habitable. It might be easier to operate solar collectors on Mercury, but life would be a great deal more difficult in every other respect.

Undeniably, solar energy is cheap and abundant. It's also inexhaustable. That's why in this world — ever closer to running out of non-renewable energy — solar energy looks like a good thing.

In Australia, many people have been using solar energy for about two decades to heat water for domestic use. The idea is catching on rapidly as the savings that are possible on a normal fuel bill become widely appreciated. Western Australia and the Northern Territory are the places where solar water heaters have become most common, for there electricity is expensive and solar energy most abundant. But, as *Ecos* 8 reported, sales of collectors are burgeoning all round the country.

These collectors are based on a simple CSIRO design developed back in the early 1950s. A blackened copper panel covered with a glass sheet absorbs the sun's rays and heats up. The heat is then transferred to water flowing through pipes attached to the copper sheet.

Simple. The system has no moving parts and, once it's installed, you can expect many years of service. It can't help but heat water, even on somewhat cloudy overcast days.



Dr Keith Cathro.

One considerable problem arises, though. Just like the billy away from the camp-fire, there's no way that these collectors can heat large quantities of water to near boiling point. While that's not so important for domestic hot water, it's a vital consideration if solar energy is to be considered for widespread industrial use.

Australian industry consumes about 40% of the nation's energy, compared with only about one-tenth that amount by domestic users. More significantly, a survey by Dr David Proctor and Mr Roger Morse, of CSIRO, showed that of the energy consumed by one of our major industries — the food industry — 90% was in the form of heat. Food processors mostly employ heat for cooking, bottle washing, pasteurization, and sterilization, as well as other less common tasks. Practically all of the heat is used at temperatures below 150°C, and about 70% of it performs its duty at less than 100°C.

Putting on the heat

What we need, if we are to cater for as many industrial users as possible, is a collector that can efficiently provide temperatures of around boiling point, perhaps even higher. Not only do applications such as providing industrial-process heat then become technically feasible, but so do undertakings such as air-conditioning.

Many scientists around the world are trying to make such a collector. Actually, quite a number have claimed they already have. But a big qualification needs to be added — cost. At the moment, these collectors are too expensive to be used for anything but demonstration systems. The market-place is still waiting, money in hand, for the arrival of a cheap high-temperature collector.

What are the problems involved in getting our billy to boil? At the CSIRO Division of Mineral Chemistry, Port Melbourne, Dr Keith Cathro is one of those devoting his efforts to help develop the second-generation collectors. He is concentrating his attention on making better absorber surfaces that will allow higher temperatures to be more easily achieved.

To try to produce an improved collector, you have to appreciate what is wrong with the old ones, Dr Cathro explains. As you try to push the temperature of a standard collector higher, the heat losses from the collector begin to increase. This means that less heat is captured in the water for useful storage and the efficiency of the collector falls. At a certain point, generally less than 80°C, the amount of heat lost nearly equals the amount supplied from the sun.

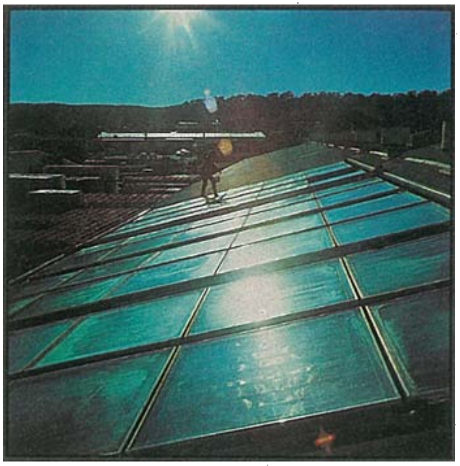
Under these conditions, the efficiency of the unit approaches zero. The temperature can rise no higher and no useful amounts of heat can be tapped off.

Where does it go?

So where does the heat go, if it's all disappearing? Dr Cathro points out that heat can be lost in several ways. If we can minimize each one, our collector will be more efficient and its useful operating temperature can be raised.

The most obvious loss is by conduction. As well as heat travelling to the pipes carrying the water to be heated, heat can be conducted to the base and edges of the collector, where it is carried away by the wind and by radiation to the surroundings. To combat this loss, ample amounts of good insulating materials such as rock-wool, fibreglass, or polyurethane foam need to be used.

Heat losses from a collector's sides and back are significantly reduced by a 'structurally integrated' collector recently designed by Dr Jeff Symons of the CSIRO Division of Mechanical Engineering. The prime feature of the unit is that the collector can be incorporated into a roof at the same time as the roofing structure is being erected, thereby saving both material and labour



Collectors with a 'copper black' selective surface operating on the roof of a soft-drink factory at Queanbeyan, N. S. W.

costs. The collector's acrylic cover becomes the roof surface, and heat losses are minimized because the back of the collector is out of the wind — it's inside.

More difficult problem

Convection is another significant heat-loss mechanism. It is the process in which air picks up heat by contact with a surface and carries it away.

One of the reasons why normal collectors have a glass cover is to prevent air racing off too quickly with heat from the black absorber surface. (Another reason is to stop radiation losses.) As it happens, the cover soon heats up and we start losing heat by convection and radiation from that. Doubly glaze the collector, and the same thing happens with the second glass cover, although at a much reduced rate.

If double glazing is needed, Dr Cathro advocates the use of glass that absorbs little of the sun's rays (that is, it's highly transmitting). More heat then gets through to the metal plate because less absorption and heating up takes place in the glass.

Australian window-glass, because of its iron content, is only about 80% transmitting, leading to considerable absorption losses. Because of these losses, Dr Cathro believes that doubly glazing a collector for domestic use with Australian glass will improve efficiency very little compared with that of a singly glazed one.

Imported 'water-white' glass will transmit more than 90% of the sun's rays and, if it's combined with a special anti-reflection coating, a figure of 95% can be reached. Cost, of course, is one deterrent.

Nevertheless, a double-glazed collector using low-iron glass has been developed by the CSIRO Solar Energy Studies Unit and Beasley Industries Ltd. It is being used in a demonstration process heating system at a brewery in Adelaide.

Other measures to reduce convection include the simple one of shielding the collector away from the wind. A more complex solution is to break up the air space between the metal plate and the glass cover plate into small honeycomb cells. Transparent plastic materials, it has been suggested, would make it more difficult for convection currents to get moving. However, the discouraging news is that no commercial collectors incorporating the idea are yet available, despite considerable work on them in the United States.

Nothing in it!

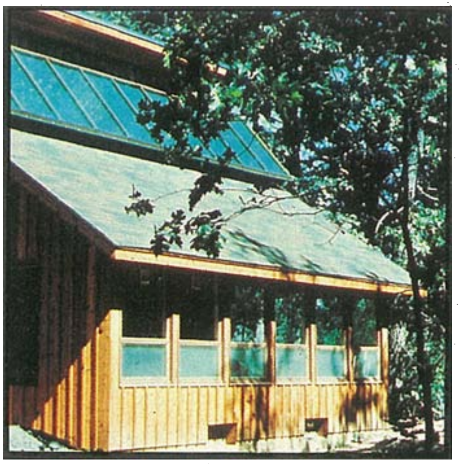
Of course, the most effective way of avoiding the problem of air-borne heat losses is to remove the air altogether! Creating a vacuum between the absorbing plate and the glass sounds easy, but it's easier said than done. For a start, there's the practical problem of preventing the cover glass from breaking under the pressure of the outside air. As well, the vacuum — less than 1/100 000 th of atmospheric pressure — must be maintained for the life of the collector — say, 20 years.

The market-place is still waiting, money in hand, for the arrival of a cheap high-temperature collector.

The standard solution is to use a tubular glass construction. Glass can be effectively sealed against air leaks, and the circular shape has strong resistance to the compressing force of the air. Fluorescent light-tubes show that it can be done in mass production manufacture.

Glass tubular collectors have caught a lot of attention for high-temperature applications. Overseas, large companies such as Philips, Corning, and Owens-Illinois have developed their own versions, and in Australia the best-known model is probably the one produced by the University of Sydney. This unit, shown in the photograph, has a special absorber that, in full sunshine, allows a theoretical maximum temperature of about 300°C to be reached. It has attracted large financial backing from the New South Wales government and from Saudi Arabia.

A rig at the Division of Mechanical Engineering testing the efficiency of the solar collector built by Dr Cathro. The rig automatically follows the position of the sun and can test collectors to 300°C.



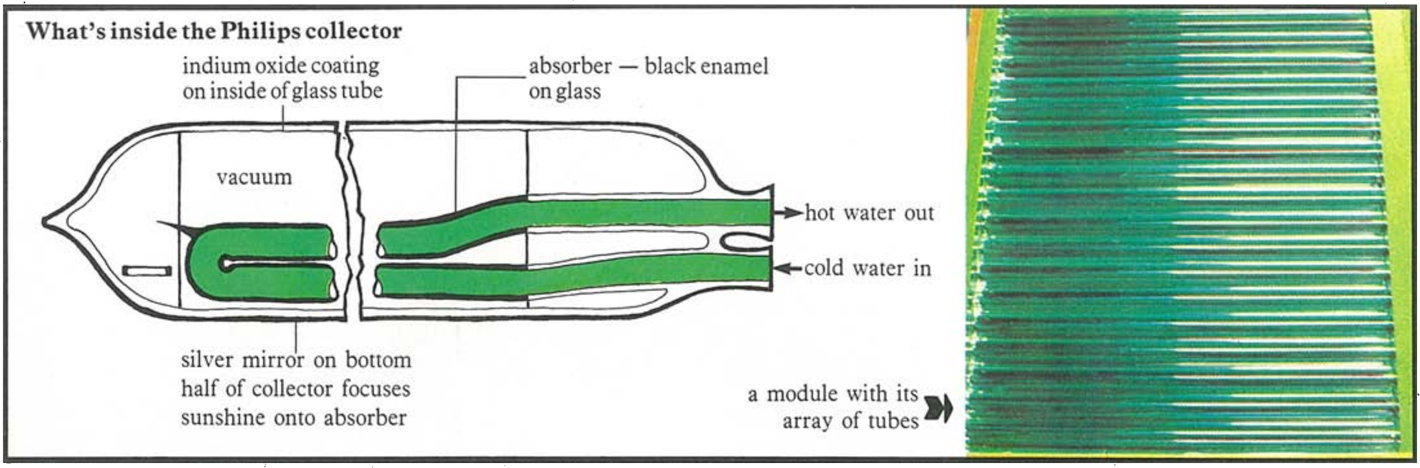
Solar collectors at work on a house in the United States.

Dr Cathro has also recently built a tubular collector. It was designed by the Divisions involved in solar collector research — Mineral Chemistry, Mechanical Engineering, and the Solar Energy Studies Unit.

The major differences between these tubular glass collectors reside in the type of absorber material they employ. That's the really interesting part and we'll talk more about it later.

A number of evacuated collectors share the feature of having cylindrical absorbing surfaces. One half of the absorber is therefore always shaded from the direct sun. To improve efficiency, and reduce cost, the tubes are spaced apart, with some kind of reflector behind them to reflect sunlight, passing between them, onto their backs. There is always a compromise between tube spacing and the type of reflector. The simplest configuration is to space the tubes one diameter apart in front of a white-painted surface.

No matter which compromise is chosen, these tubular collectors are seldom as efficient as ordinary flat-plate collectors for producing quantities of low-temperature water using strong sunshine. But, because of their low losses, these advanced collectors will perform much better in heating water above boiling point on cloudy days. Their heat loss will be typically about one-fifth that of the better conventional flat-plate collectors.



The Philips evacuated-tube collector uses a specially coated glass to trap heat. The coating allows the sun's rays to pass through to the absorber, but any heat emitted is reflected back by the coating.

Radiation

After looking at conduction and convection losses, let's look now at that elusive beast, radiation loss. It's a subject close to Dr Cathro's heart, since most of his work is concerned with developing special absorber surfaces called 'selective surfaces', which minimize this loss.

As we said earlier, one of the functions of a collector's glass cover is to reduce radiation losses. The glass turns the collector into a little greenhouse — it lets the radiation from the sun pass through to the absorber panel, but prevents heat radiation from passing out again.

The reason why glass can perform this trick is that the two sorts of radiation involved cover different wavelength ranges. Allowing for absorption in the atmosphere, the sun's energy is almost entirely confined to a band of wavelengths ranging from the ultraviolet (0·3 micrometres), through the visible spectrum, to the infra-red (2 micrometres). The diagram — see page 20 — shows that most of the radiation pours down at around 0·5 micrometres in the visible part of the spectrum. On the other hand, the heat radiated from hot solar collectors has a wavelength range of from 2 micrometres to more than 20 micrometres. Luckily, the two regions overlap very little. Now glass is substantially transparent over the whole of the solar spectrum, but opaque above about 2·5 micrometres. Consequently the short-wavelength radiation passes through, but the long-wavelength (heat) radiation is trapped.

Australian window-glass, because of its iron content, is only about 80% transmitting, leading to considerable absorption losses.

Note, though, that the 'trap' is not perfect. The glass absorbs the long-wave radiation, and heats up. Convection from the glass surface can then act as an escape route.

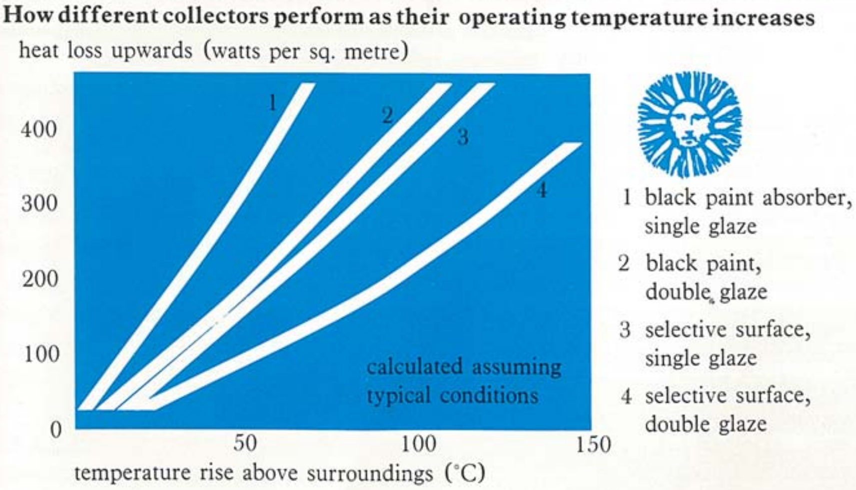
If, however, the glass were a reflector for thermal radiation, rather than an absorber, then it would create a real solar trap. It would reflect back onto the absorbing plate any heat that the plate emitted. A couple of techniques have been devised to make glass reflective to thermal radiation. They consist of applying thin coatings of material such as indium oxide. Philips have used such a method. However, their worst feature is that they also block off some of the solar radiation. Typically, a glass cover coated with such a film transmits about 15% less sunlight than does the glass by itself.

Keeping the heat in

Instead, most of the effort has concentrated on improving the performance of the surface on the absorber plate. The simplest absorber material is standard black paint. It is black just because it absorbs most of the incident visible light, so it will work as a solar collector. But the laws of physics tell us that a perfect absorber for all wavelengths is also a perfect emitter. This explains why black paint, a good absorber for both light and

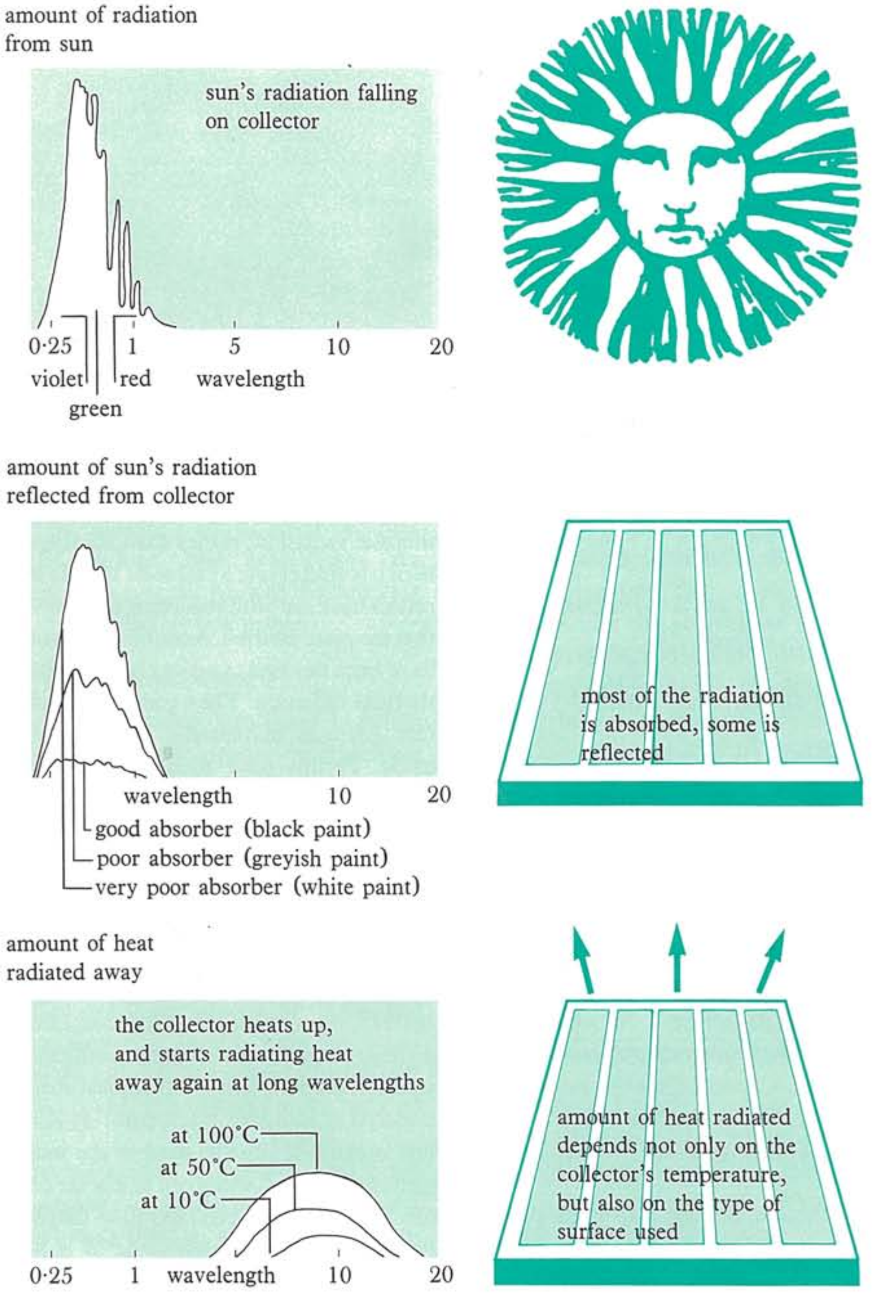
The University of Sydney's solar collector is an evacuated-glass-tube type. Its absorber surface is a layer of minute iron and iron carbide particles.

How different collectors perform as their operating temperature increases



Simple collectors are adequate at low water temperatures, but at higher temperatures more sophisticated designs are needed.

How a solar collector collects (and loses) radiation



Different collector surfaces compared

	amount of sun's radiation reflected	amount of heat radiated away (at 100°C)*
ideal selective surface	0% (all absorbed)	0%
chrome black	4%	6%
copper black	13%	5%
nickel black	12%	6%
black paint	5%	38%
perfect 'black body'	0%	40%

*as a percentage of radiation received

He has developed a way of producing a stable, selective surface on galvanized iron simply by immersing it in a chemical bath.

heat, unfortunately also emits a lot of heat.

What we need is a material that is a good absorber of light, but a poor emitter of heat — a so-called 'selective' absorber. The ideal selective material would absorb 100% of the visible spectrum and emit 0% of long-wave radiation. Of course, nothing in this world is ideal, but it is possible to get close to this situation. Good selective surfaces can be made, which will reduce the collector's heat loss by one-half, or better. This is done by combining two materials — one a good absorber, the other a good reflector.

In general, metals are good reflectors of radiation — they make excellent mirrors. On the other hand, non-metals are good absorbers. We therefore have two different ways of making a selective surface.

Coating a metal . . .

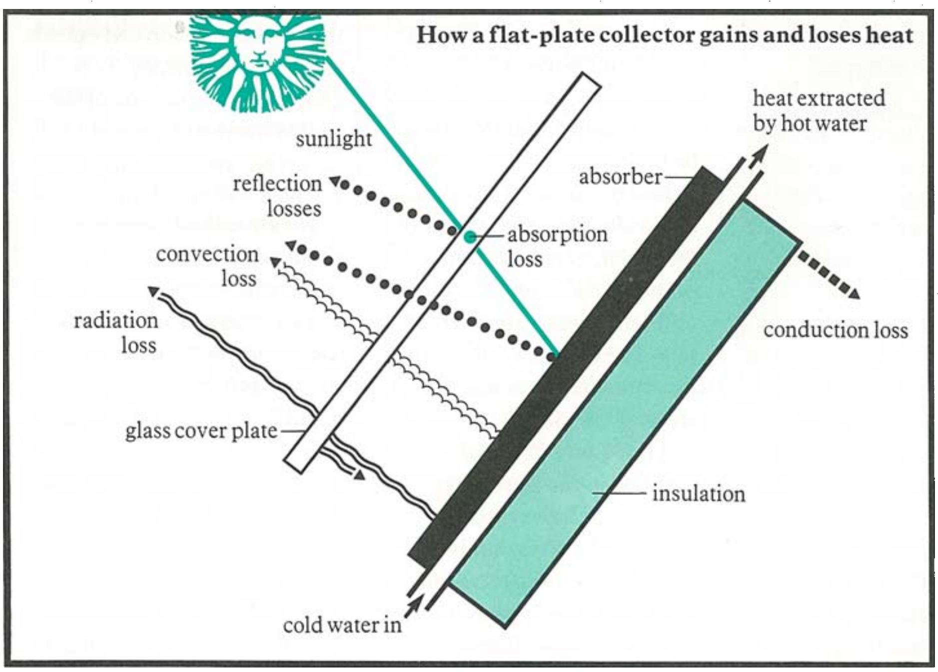
One way is take a polished metal base and coat it with a very thin non-metallic surface — only about 1 micrometre thick. Visible light trying to penetrate the layer gets absorbed because its wavelength is only about half that. However, long-wave radiation (heat) has a wavelength many times that thickness, so it easily penetrates the layer and is reflected by the metallic base. Being a good reflector of heat, the surface is also, according to physics, a poor emitter of heat. We therefore have a selective surface.

Such a surface is the layer of copper oxide on copper known as 'copper black'. This was developed in 1964 by the CSIRO Division of Mechanical Engineering and is currently used on commercially available flat-plate collectors. The treatment is simple — the completed copper absorber plate is dipped in an alkaline bath of sodium chlorite.

Two years ago, a colleague of Dr Cathro, Dr Alan Reid, found that the copper black could be made more durable by immersing it in a second bath of ammonium chromate solution. In addition, this increased absorption of sunlight from 88% to 93%, while it reduced heat radiated from the surface from 8% to 6% of the worst possible loss. Beasley Industries have developed the new coating for commercial use on their collectors. The firm is now licensing Japanese companies to use its method of application.

'Nickel black' is another good selective

Removing a collector from an electroplating bath where it has been surfaced with 'chrome black'.



How a flat-plate collector gains and loses heat

coating. It is actually a nickel–zinc–sulphide complex produced by electroplating. In Israel, most of the collectors produced over the last few years have had a nickel black surface on a galvanized iron base.

Dr Cathro has experimented with different ways of producing nickel black coatings. Recently he has devised a technique that has aroused considerable commercial interest. He has developed a way of producing a stable, selective surface on galvanized iron simply by immersing it in a chemical bath. He calls this coating 'chemical nickel black' and it has the advantage of doing away with touchy electroplating baths and their associated equipment. It promises to markedly reduce the cost of solar collectors, according to Dr Cathro.

. . . or a non-metal

The other way of making a selective surface involves taking a dark-coloured base and covering it with a layer of finely divided metal. For visible light, the small metal particles are black (like silver in a photographic negative); but at longer wavelengths the true reflecting character of the metal dominates.

'Chrome black' is an example of this type. It has recently been discovered to be a good selective surface, although it has been used for many years as a decorative finish! The electroplated surface contains particles of chrome metal in a chrome oxide matrix. The surface shows the same excellent durability as decorative bright chrome and it is now widely used in the United States.

Dr Cathro has investigated the properties of chrome black and methods of applying it, and his assessment is that its performance is hard to beat. It boasts a solar absorption of 96% or more and can withstand temperatures of at least 200°C. The CSIRO evacuated collector, mentioned earlier, uses a chrome black surface electro-deposited onto a nickel-plated copper base.

The University of Sydney's evacuated collector uses small particles of iron and iron carbide as the selective surface. These are deposited on the glass by a process called sputtering — splashing caused by the impact of ions with a high-voltage electrode. The process needs to take place in a closely controlled vacuum, but leads to a very tenacious durable coating.

The other overseas evacuated collectors — Corning, Owens-Illinois, and Philips — employ different materials: copper oxide, chromium oxide, and indium oxide and black enamel, respectively. Other types of selective surface are also under development.

Which collector type will finally make it to the mass market is impossible for Dr Cathro to say at this stage. And there are some collector types we haven't mentioned — such as focusing and sun-tracking collectors. Nevertheless, the main contenders are certainly receiving sufficient attention to ensure we'll hear more of them.

With a combination of the techniques mentioned, it may even be possible to boil water at ten paces from a camp-fire. . .

More about the topic

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