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USE OF PLASTICS IN SOLAR ENERGY APPLICATIONS

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Abstract—A discussion of the state-of-the-art on the use of plastic materials in solar energy applications is presented, with particular emphasis on their suitability and durability. The availability of plastics in many types and shapes (including sheeting material, films and foams) accounts for the wide range of current and potential applications in solar energy installations. Consequently, actual and potential uses of plastics include: covers (glazings), honeycomb structures and housings for flat-plate collectors; reflecting surfaces, optical lenses, shells, structural and support members for solar concentrating collectors; and insulation and piping. The plastics that have been discussed in this article in relation to their use as components in solar installations include poly(methyl methacrylate) (PMMA), polycarbonate (PC), glass fiber-reinforced polyester (GRP), poly(vinyl fluoride) (PVF), fluorinated ethylene–propylene (FEP) copolymer, poly(ethylene terephthalate) (PET) and various foamed plastics.

The aging behaviour of most of these plastics has been widely studied for normal outdoor exposure and in artificial weathering devices, and are thus briefly described here. Very little information is available, however, regarding their short-term performance under actual service conditions in solar energy installations; none has been reported on their long-term durability.

Plastics have various degrees of flammability and therefore special care should be taken by using materials with adequate fire resistance and/or appropriate design in applications where a fire hazard may exist.

INTRODUCTION

Solar energy is the ideal source of energy for space heating and power generation: it is practically inexhaustible, is easily converted and its use does not result in pollution. Efforts to harness solar energy have been accelerated during the last decade as world demand for energy grows.

Although solar energy is "free", the cost of making and installing the systems to harness it was, until recently, too high to be considered for residential space heating or cooling. Although the cost disadvantage still exists, each year the economics of solar heating installations become more attractive. One reason for this is the increasing use of plastic materials in the manufacture of various components of solar heating devices.

The purpose of the present article is to present a critical discussion of the state-of-the-art on the use of plastics in solar energy installations, with particular emphasis on their suitability and durability.

A complete solar energy heating and cooling installation consists of an energy conversion system or collector, a transfer fluid (e.g. water, air, glycol), storage tanks and pipe work. There are two main types of design of collectors: the flat-plate collector and the concentrating collector. The flat-plate collector is best suited for limited heating–cooling installations, for example, in residential buildings or small industrial or community applications; the concentrating collector is designed for use in large-scale power generation.

A flat-plate collector generally consists of five components (Fig. 1): one or more covers; an absorber plate, generally metallic; a tube or pipe for conducting or directing the heat transfer fluid; insulation to minimize the downward heat loss from the absorbing plate; and housing or casing which encloses the foregoing components and keeps them free of dust and moisture as well as reduces the heat loss. Generally, flat-plate collectors are framed sandwich structures and are mounted on roofs or sloping walls. A large number of types and variations of experimental and practical flat-plate collectors are available[1–6].

A concentrating (focusing) collector operates as an optical system in which the solar radiation received is concentrated onto a small area (absorber) to produce thermal or electrical energy[4–6]. It is believed that at least one type of concentrating solar collector[7] could be used for space heating and cooling at an initial installation cost only marginally higher than for a conventional flat-plate collector. Although there are many designs for concentrating collectors[2, 6, 8, 9], they can be classified into two types, depending on the method used for increasing the flux of solar energy on the absorber. In one type, the concentration of solar energy is accomplished by reflecting it from a mirror-like surface. The other type is equipped with a lens system in which the radiation passing through is focused on the absorber.

As the temperatures needed for space heating and cooling are relatively moderate[3], plastics are being

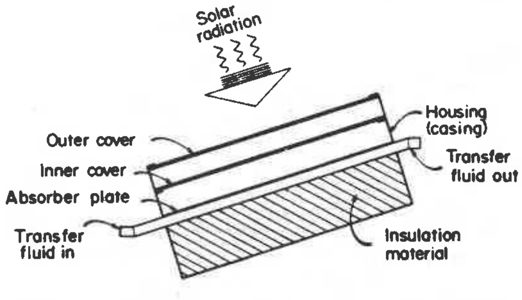

Fig. 1. Schematic cross-section of flat-plate collector unit.

used or are being considered as potential materials for the construction of most of the component parts of the flat-plate collectors and auxiliary parts. In concentrating collectors, however, the operating temperatures are considerably higher[6, 8] and plastic materials are used to a lesser extent.

PLASTICS VS TRADITIONAL MATERIALS

Plastics, as relatively new materials, are less well understood than traditional ones[10, 11]. They have many outstanding advantages over other materials, but also have several drawbacks. An important advantage is that as their density is lower than most engineering materials, they have higher strength-to-weight ratios, a useful feature where reduction in weight is required. The resistance to erosion of many plastics is superior to conventional materials[12] and they usually provide better heat and sound insulation than metals. Items made from plastics often have a more attractive appearance than those derived from most materials: they can be opaque, translucent or transparent. Plastics can be molded, extruded, thermoformed or machined into a wide range of intricate shapes and they generally are very amenable to prefabrication economically by mass-production techniques, an important feature in many applications. The mechanical properties of plastic materials are much more dependent on the temperature and rate of application of stress than are those of metals[13, 14]; their deformational behaviour depends not only on the magnitude of the stress but also on the length of time it is applied.

Plastics can basically be classified into two groups: thermoplastic and thermosetting materials[15, 16]. Thermoplastics soften when heat is applied and exhibit considerable creep under load, particularly at elevated temperature. Consequently, when thermoplastics are used in a solar energy collector, they must be incorporated in such a way as to avoid approaching the heat-softening point. Thermosetting materials (once cured) do not soften appreciably on the application of heat; they normally exhibit higher strength and have less tendency to creep than themoplastics. They are, however, more brittle and thus cannot be used structurally without reinforcement. Creep effects in plastics generally may be significant even at room temperature, whereas in metals they are not important at temperatures below 500°C (932°F).

Although some plastics have better wear resistance than metals, most have very low resistance to scratching and abrasion. However, transparent plastics can have varying degrees of toughness and flexibility, an advantage over glass.

Plastics are generally affected to a greater extent than traditional materials by the elements of the outdoor environment, more particularly by the UV portion of the solar radiation. Some however, have intrinsically good resistance to weathering; others weather poorly, but can be made weather resistant for a reasonable time by incorporating additives.

A serious drawback of most plastics is their low fire resistance but varying degrees of fire resistance can be achieved with most flammable plastics by incorporating additives. If plastics are to be used in a location where a fire hazard may exist, only those with adequate fire resistance should be considered and/or care taken to ensure adequate fire resistance through design. The products of combustion must also be considered in their application.

PLASTICS IN SOLAR ENERGY APPLICATIONS

The availability of plastics in many types and shapes, including sheets and films, accounts for the wide range of current and potential applications in solar-energy applications, for example, as covers, thin-film honeycombs and housing for flat-plate collectors, reflecting surfaces and optical lenses for concentrating collectors, reflector shells, structural and support members, insulation and piping. Once in service, most structures made from plastics require less maintenance than those produced from other materials. Thus, in the field of solar applications, plastics are strong competitors with common traditional materials such as glass, metals, wood and concrete.

Covers in flat-plate collectors

Collector covers (glazing) are sheets or films that transmit nearly all incident solar radiation, but block passage of longwave radiant (thermal) energy and convected heat from the collector to the outside, so that a greenhouse effect is produced.

Glass, owing to its earlier availability and highly desirable properties has been the material most commonly employed thus far to glaze flat-plate solar collectors[3, 6, 17, 18]. Glass can transmit up to 91 per cent of the impinging shortwave radiation (from 0.3 to 3.0 μm) at normal incidence, while virtually not allowing any longwave radiation (3.0–30 μm) emitted by the absorber to escape outward by transmission[3]. Furthermore, it has good weatherability. Glass, however, is not entirely satisfactory for use as glazing in solar collectors. Its low impact strength, which makes it very susceptible to easy breakage by hailstone or vandals, is its most serious drawback. Other disadvantages are its relatively high density and poor resistance to thermal stresses. In addition, glass absorbs longwave radiation (heat) emitted by the absorber plate. This causes the temperature of the glazing to rise, resulting in heat loss to the environment. Use of an IR reflective coating to reduce this heat loss decreases the effective transmittance by as much as 10 per cent[3] and increases cost.

With their relatively light weight, better shatter resistance than glass, ease of fabrication and good transmission of solar radiation, some plastics have been used as glazing in collectors for residential heating and cooling or as covers in solar stills. Plastics are generally more transparent than glass; some have a solar transmission as high as 97 per cent (Table 1). Unlike glass, however, they are in general partially transparent to longwave radiation[5, 6, 23]. The transmission of IR radiation is variable, depending on the thickness and molecular structure of the plastic material. Plastics may be either sheets (1.00–3.2 mm; 0.040–0.125 in.) or thin films (0.025–0.125 mm; 0.001–0.005 in.). The IR transmission (2.5–

Table 1. Guide to the properties of sheet and film materials used in solar energy applications [19, 20]

Type of Material	Thickness,† mm (in.)	Specific Gravity (ASTM D792)	Weight, $kg\ m^{-2}$ ($lb\ ft^{-2}$) for thickness of Column 2	Transmission of Solar Radiation, %	Resistance to (Continuous) Heat, Max. Temp., °C (°F)	Tensile Strength (ASTM D638) MPa (10^3 psi)	Modulus of Elasticity (ASTM D638) GPa (10^5 psi)	Thermal Expansion Coeff. (ASTM D696), 10^{-5}/°C	Applications (Experimental or Actual Installations)
PMMA	3.2 (0.125)	1.17 - 1.20	3.7 (0.75)	89	60 - 95 (140 - 203)	72.4 (10.5)	3.1 (4.5)	5.0 - 9.0	Mainly as lenses in concentrating collectors; also flat-plate collector cover (glazing) material.
Poly-carbonate	3.2 (0.125)	1.20	3.8 (0.77)	82 - 89	120 (248)	65 (9.5)	2.1 - 2.4 (3.0 - 3.5)	6.6	Glazing and honeycomb structures.
GRP	1.0 (0.04)	-	1.5 (0.30)	80 - 90	150 - 175¶ (302 - 347)	100 - 120 (15 - 17)	7.6 (11)	3.6 - 4.4	Glazing and honeycomb structures.
PVF	0.10 (0.004)	1.38 - 1.57	0.14 (0.028)	92 - 94	108 (226)	90 (13)	1.8 (2.6)	4.8	Glazing for collectors and solar stills; honeycomb structures; substrate in mirrors of concentrating collectors.
FEP	0.05 (0.002)	2.12 - 2.17	0.10 (0.02)	97	205 (400)	19 - 21 (2.7 - 3.1)	3.4 (5.0)	8.3 - 11	Glazing for collectors and solar stills; honeycomb structures; substrate in mirrors of concentrating collectors.
PET	0.025 (0.001)	1.38 - 1.40	0.034 (0.007)	85	104* (220)	170 (24)	3.8 (5.5)	3.0	Honeycomb structures; substrate in mirrors of concentrating collectors.
Glass, water white (0.01% iron)	3.2 (0.125)	2.46 -2.49Π	8.1 (1.65)	85 - 91	205* (400)	11 (annealed) (1.6) 4.4 (tempered) (6.4)	724 (105)	0.85Π	Glazing.

† Thickness may vary with type of application
Π Taken from reference 21.
¶ One year heating at 93°C (200°F) has resulted in a 10% solar transmission reduction even in solar grade sheet (22).
* Max. operating temperature.

15.0 μm wavelength region) curves of a number of plastics has been reported, the thicknesses of the samples being typical of those used in solar collector experiments[5, 23].

The plastics most commonly used for glazing in solar collectors are: poly(methyl methacrylate) (PMMA), polycarbonate (PC), glass-fiber-reinforced polyester (GRP) sheeting, and films of poly(vinyl fluoride) (PVF) and fluorinated ethylene–propylene (FEP) copolymer.

As the thickness of the plastic sheet or film increases, the material becomes more opaque to IR radiation. In thicknesses used in solar collectors[5], poly(methyl methacrylate) and glass-fiber-reinforced polyester sheets are more opaque to IR radiation than glass; polycarbonate shows some transmission up to 6 μm; polyethylene is the most transparent.

PMMA and PC sheet

These are used as general glazing in institutional and industrial buildings[24]. Covers made of either of these plastics weigh only half as much as those of similar thickness made of glass. PMMA and PC are good insulators and have relatively high initial transmission of solar radiation (Table 1). PMMA sheet (commonly referred to as acrylic) has particularly good properties, e.g. it has better break resistance than glass, its transmission is the equal of the best low-iron glass[24] and is one of the most weather-resistant plastics[25–27]. The pure polymer is not affected by UV light down to 0.285 μm. If colour develops, it is believed to be caused by the presence of impurities or additives incorporated during the processing of the plastic. Although its resistance to natural outdoor exposure is well known, its long-term durability under conditions prevailing in a flat-plate collector has not been reported.

PMMA has a relatively low softening point and thus it undergoes large distortion when used as inner glazing material[28]. Therefore, PMMA inner glazings should be shielded from radiation during stagnant periods.

Polycarbonate sheet has one of the highest initial impact strengths of all plastics[24], but also has very low mar-resistance. Mar-resistant types are available, but they do not weather well. Polycarbonate sheets have lower solar transmission than those of PMMA, but they have considerably higher heat resistance (Table 1). Outdoor weathering induces surface micro-cracking in standard, UV-stabilized polycarbonate glazing after a relatively short period of exposure[29]. The surface deterioration, caused by solar radiation in conjunction with moisture and/or temperature-induced stress-fatigue, results in gradual impairment of mechanical properties such as tensile[30] and impact strength. Thus the existing commercial polycarbonate glazing material is still not adequately protected against the effect of radiation.

Glass fiber-reinforced polyester (GRP)

GRP sheeting has a combination of interesting properties including light weight, strength, good impact resistance over a wide range of temperatures, relatively high light transmission and better heat resistance than most other plastic-based materials. It is particularly suitable for use as roof lighting and glazing for industrial (factories, warehouses, greenhouses) and community buildings (sports arenas, swimming pools). The initial solar transmission depends on formulation and method of fabrication.

When exposed to the outdoor environment, however, GRP sheeting generally undergoes deterioration in properties[31]. In particular, the surface of the sheet develops fiber prominence ("fiber pop out") and microcracks[32], both of which impair the appearance of the GRP sheet. The scattered fibers and the irregular surface of the cracked resin diffuse some of the incident light, thus causing a reduction in light transmission properties of the sheet. Surfacing of the GRP sheet with poly (vinyl fluoride) film considerably improves the resistance to surface erosion by outdoor exposure[33]; one such type of GRP sheeting is now being evaluated as glazing in a flat-plate solar collector[34].

The feature that makes GRP material desirable as solar glazing is its high transmission over the typical solar spectrum and its near opacity to longwave radiation[5, 22]. A GRP material highly stabilized to resist UV light degradation has recently been developed specifically for solar heating collector covers[22, 35]. The resistance to deterioration relative to other grades of GRP sheet has been assessed[22] by subjecting it to artificial weathering (fluorescent weathering machine), heat aging (1 yr in an oven heated at 93°C; 200°F) and to outdoor exposure (facing south for 5 yr) in southern Florida. Results indicate that the solar grade performs considerably better in all of these exposures than the other two UV light-stabilized grades, the acrylic-modified and standard grades. The properties assessed were color, per cent solar transmission and surface erosion. South-facing exposure in southern Florida is considered to be a severe natural weathering test, because of the total quantity and intensity of sunlight and large quantities of heat and moisture. Evaluation of durability by outdoor exposure in this or other geographical locations is, however, not entirely satisfactory for assessing performances of GRP as solar covers. Ideally, the long-term performance of any plastic, including GRP sheet, should be assessed in service, i.e. in a solar collector, where it is subjected to relatively high temperatures, cyclic variations of temperature between day and night, sunny and cloudy days, and variations of humidity and in intensities of solar radiation.

Fluorine-containing plastics

Plastics based on fluorine-containing polymers have high thermal and chemical stability, low water absorption and excellent weather ability[25, 36]. Two fluorine-containing plastics, poly(vinyl fluoride) (PVF) and fluorinated ethylene–propylene (FEP) copolymer, when used as thin film (up to 0.250 mm; 0.01 in.) have very high transmission, and thus have been used as covers of solar collectors[35, 37].

PVF film has remarkable retention of appearance and physical properties after long exposure to outdoor weathering and has very good resistance to abrasion, chemical and staining. Thus, the largest commerical use of

PVF is to provide a protective and strain-resistant surface to building products[36, 38], e.g. weather-resistant surface for industrial roofing, house sidings and glass-reinforced plastic panels. For solar applications, it is available in thicknesses of 0.1 mm (0.004 in.), with an initial solar transmission of 92–94 per cent; it retained 95 per cent of its transmission after 5 yr of Florida exposure[19, 36]. PVF film is also used as cover in solar stills[36, 39].

Films of FEP plastics have slightly better initial transmission (up to 97 per cent)[19, 35, 37] and similarly good retention of properties even after long exposure to outdoor weathering in Florida[23].

Plastic honeycombs

The use of transparent honeycomb structures between the absorber plate and the transparent cover contributes significantly in increasing the efficiency of conventional flat-plate collectors[40] by suppressing the heat loss (convective and radiant). These structures may be made of glass or plastic; some plastic honeycombs can be conveniently and economically mass-produced. Various studies have been carried out recently to investigate the suitability of using plastic honeycombs in flat-plate solar collectors[41–43]. In one such study[43], plastic thin-film (0.025–0.1 mm; 0.001–0.004 in.) honeycombs have been evaluated under outdoor weather conditions in high performance flat-plate collectors operating in the temperature range of 40–120°C (104–250°F). The plastic honeycombs tested were based on polycarbonate, poly(ethylene terephthalate), poly(vinyl fluoride), fluorinated ethylene–propylene copolymer and polyimide polymer. Flat-plate collectors fitted with plastic honeycomb devices performed considerably better than collectors without such modification; thermal energy efficiencies were more than 50 per cent higher for temperatures up to 110°C (230°F). Polycarbonate and poly(ethylene terephthalate) provided the highest efficiencies. With a honeycomb collector, only one glazing sheet is required to achieve maximum efficiency. In addition, a plastic honeycomb collector with a conventional black plate absorber will give equal or better performance than a non-honeycomb collector fitted with a selective black plate absorber. Preliminary cost studies carried out in this investigation indicated that some plastic honeycomb collectors present a substantial, initial installation cost advantage over the non-honeycomb collectors. Although the study is quite extensive and gives detailed information, such as material physical properties, thermal balance-analysis and collector fabrication details, results of the actual performance testing of the honeycomb collector in the outdoor weather under operating conditions covers only a 3-month period. This testing period is too short to allow valid prediction of its long-term performance.

Plastics in concentrating collectors

The principal applications of plastics in concentrating collectors are in the fabrication of lenses[5, 44–46] and reflecting surfaces[4, 47–49]. Other uses are as materials for the reflector shell and for supporting structures for concentrating collectors[48].

Ordinary glass lenses are seldom used in solar refractors because their weight and cost are serious disadvantages[5]. The most commonly used lenses are those of the Fresnel type (with either circular or cylindrical symmetry) which, for solar energy applications, are generally made from plastics[5, 44–46]. Fresnel lenses used in operational or experimental concentrating collectors are made of optical grade PMMA-based plastic. In addition to their high transmission and good weathering resistance, these lenses can be conveniently and economically mass-produced by casting[44, 46] or by compression molding.

The fabrication of Fresnel lenses by casting from a liquid or by compression molding involves lower temperatures than for the production of glass lenses. The lower temperature and lack of flow after setting results in lenses with sharp corners and highly polished surfaces.

Although PMMA plastic weathers well, its resistance to outdoor exposure is lower than that of glass. Furthermore, PMMA articles are easily scratched and undergo pitting from airborne particles such as sand and dust. In solar refractors, the radiation passes through the lens material only once without change in its intensity, and thus does not cause any significant increase in the temperature at any point of the optical system. Thus, outdoor weathering results obtained by exposing sheet material on conventional racks should be valid for estimating the long-term performance of a plastic as optical lens in solar reflectors.

Recently, a pertinent study was reported of the effect of outdoor weathering on the properties of PMMA sheet exposed for almost 18 yr in a semi-arid desert location in the southern United States (Albuquerque, New Mexico)[27]. SEM examination of the exposed side of the weathered sheet (3.2 mm thick; 0.125 in.) indicated that it had undergone considerable erosion and pitting. The light transmission of the weathered sheet was reduced by 10 per cent of its initial value. When the exposed side of the sheet was polished to remove the damaged surface layer of the material, the transmission loss was only 3 per cent. Measurement of mechanical properties of the sheet, however, showed a significant deterioration. For example, the flexural strength decreased by about 50 per cent. The drastic reduction of this property may be due to the deterioration of a relatively thin surface layer of the plastic sheet. Indeed, a study performed in this laboratory[29, 30] demonstrated that in a weathered sheet (3.0 mm thick; 0.125 in.) of polycarbonate, which like PMMA is a thermoplastic material, a very thin layer of deteriorated surface resin on the exposed side results in a relatively large reduction in mechanical properties. The exposed surface of the lens can be protected with a thin coating of an UV- and abrasion-resistant coating to reduce or prevent surface damage (erosion, scratching, pitting). In addition to reducing transmission loss due to scatter, this modification of the surface would also prevent deterioration of mechanical and other physical properties. The modified material would also perform better when used as solar cover in flat-plate collector or as mirror substrate in reflectors. One such coating, based on a crosslinked poly(methyl siloxane) resin, having good abrasion resistance, was evaluated experimentally and was shown to improve transmission efficiency of PMMA lenses[27].

Reflecting optical devices for solar energy applications can be made from a wider range of materials than is possible for transmission optics because there is no need for them to be transparent. The materials should have a surface with good polish so that the rays are specularly reflected with little scattering of light. Furthermore, reflecting surfaces of mirror materials should be dimensionally stable and retain their high specular reflectivities for a relatively long time with reasonable maintenance. Loss of reflectivity can result from surface degradation, erosion, dirt accumulation and action of cleaning agents.

Metals can serve as mirrors since they are intrinsically reflective. Optical polishing, however, of all highly reflective metals is extremely difficult, especially when cylindrical or spherical mirrors are made, and, therefore, very costly.

For some applications, back-silvered glass has served well and has good weatherability. Its use is limited, however, by its poor resistance to shock, particularly where movable surfaces are concerned. Furthermore, glass cannot be fabricated without difficulty into large, thin panels that might have to be curved or have complex cross-sections.

Commercial plastics do not have a surface finish sufficiently smooth to be used as efficient reflectors[48], but they can be a good substrate for a reflector mirror. A metallic surface finish (thin coat) is applied to a plastic substrate by chemical or vacuum deposition. Silver and aluminum are the most efficient reflective materials[49]. The plastic substrate may be in the form of sheet or film[5, 44, 47, 49]. Plastic films offer the attractive option of making very thin and thus lightweight mirrors. When front-surface mirrors are used, the change in transparency is not critical but the problem of bending fatigue still exists. In actual and experimental installations, plastic films are normally used with the aluminum or silver coating applied to the backside, thus functioning as a second-surface mirror. The metallized plastic films that have been used or tested for use in solar reflector applications are based on poly(ethylene terephthalate) (PET), PVF, PMMA, FEP and cellulose acetate buyrate (CAB) polymer[27, 45, 47–49]. Some data have been reported on initial total reflectivities on these metallized films[47, 49], but no results are available on reflectivities as a function of time for extended periods under service conditions. Neither is there any information on long-term weathering of these films when used in mirrors of solar reflectors. In this application, aging is greatly accelerated because the sunlight passes through the plastic twice.

Although aging of the plastics used in the fabrication of the metallized films has been studied under outdoor weather conditions and in artificial weathering devices, the information regarding their durability is not entirely valid for applications of these materials in second-surface solar reflectors. Increasing the intensity of the environmental factors in artificial weathering devices in order to accelerate the aging process is not recommended. Only some of the factors can be simulated without changing the character of the aging process; the nature of this process may be drastically altered by increasing some factors and not others. On the other hand, assessment of durability in service is not always practical because of the time and cost involved.

One method for accelerated weathering intended for assessing the durability of plastic films for mirrors of solar reflectors has been reported[50]. In this method, the specimens are placed on a special rack outdoors and are thus subjected not only to the effect of all atmospheric factors but also to the intense solar radiation produced by a concentrating solar reflector made of highly polished aluminum. Evidently, intensification of the solar radiation does not change its spectrum (frequency distribution), but results in acceleration of aging without changing the nature of the process involved. In this case, a direct relation can be established between the rate of aging of the plastic film or coating under natural conditions and the degree of intensification of the solar radiation.

Plastic foam for thermal insulation

Plastic foams are used in solar energy systems (e.g. solar heating–cooling and solar water heaters) as essential elements for maintaining the heat-retaining capacity of the installation. When used in the collector itself, these foams are often protected from the relatively high heat of the absorber by a layer of glass fibers. Foams are also used as insulation around pipes, tanks and other components of solar heating installations where heat might otherwise be lost. The most common types of foams used are polystyrene, phenol-formaldehyde, urea-formaldehyde and polyurethane[35, 51, 52]. The relatively new plastic foam based on polyisocyanurate polymer has recently been introduced as the thermal insulation in the solar collector itself[44]. Chemically related to polyurethane foam, the foamed polyisocyanurates have higher thermal stability[53, 54] and inherently better flammability characteristics than most of the common plastic foam materials[54, 56].

Halocarbon blown foams have a relatively high initial insulation value[55]. The thermal resistance changes, however, with aging and this should be taken into account in the design of the collector system[54, 55].

Because foamed plastics in general have a relatively large surface area, the problem of flammability is more acute than with bulk plastics. Thus the most flammable foam materials and sprayed foams should be placed behind a fire-resistant barrier to provide a degree of fire protection. This arrangement and other recommended practices must be observed for the safe design, handling, storage and use of plastic foams[57].

Pipe

Plastic pipe should not normally be used in the flat-plate collector itself as it cannot withstand the high temperatures experienced in continuous service. Its low thermal conductivity also excludes its use in heat-exchange units. However, low thermal conductivity, light weight, corrosion resistance and ease of installation make some types of plastic pipe very attractive for use elsewhere in solar energy installations. The two conventional hot-water types, chlorinated PVC (CPVC) [58] and polybutylene plastic pipes can be used[35].

Basic CPVC resin is made by post-chlorination of PVC. It is comparable to PVC in most properties but can withstand temperatures of up to 100°C (210°F), 35–40°C (95–104°F) higher than PVC, and is used widely in hot fluid applications[59]. The relatively new polybutylene has practically no creep and excellent resistance to stress-cracking; the high-temperature grade can resist temperatures of 105–110°C (221–230°F).

Storage and hot water tanks

Storage tanks now used are made mostly of metal or concrete. Since most solar heating systems involve relatively large storage tanks, the handling and initial installation are difficult and costly. Plastics being used or considered for use in the construction of tanks are GRP and high density polyethylene[35, 51].

SUMMARY

Light weight, high solar transmission and shatter-resistance are properties that make some plastics suitable for use as covers (glazings) in flat-plate collectors. Plastic sheets or films that have been used in experimental or actual installations are based on poly(methyl methacrylate) (PMMA), polycarbonate, glass fiber-reinforced polyester (GRP), poly(vinyl fluoride) (PVF) and fluorinated ehtylene–propylene (FEP).

Some thermoplastics can be economically mass-produced by existing techniques into thin-film honeycomb structures, which, when used in flat-plate collectors between the absorber and the cover, increase the thermal efficiency significantly. Polycarbonate and poly-ethylene terephthalate) provide the highest thermal efficiency when used in flat-plate collectors operating in the temperature range of 40–120°C (104–250°F) under outdoor conditions; thermal energy efficiencies were more than 50 per cent higher than in non-honeycomb-modified collectors for temperatures up to 110°C (230°F). Also, plastic honeycomb collectors with a conventional black-plate absorber have been shown to perform as well as, and in many cases better than non-honeycomb collectors fitted with selective black-plate absorber. Other plastics that have been evaluated as honeycomb devices in flat-plate collectors are PVF, FEP and polyimide. Although preliminary results of this evaluation are promising, the testing period in the actual collector is too short for valid prediction of long-term performance of any of these plastic honeycomb devices.

The principal use of plastics in concentrating collectors is in the fabrication of lenses and reflecting surfaces. The commonly used Fresnel lenses are made from PMMA plastic, a material with very good weather-resistance and high solar transmission. These lenses are mass-produced economically. If their surfaces are protected by an UV- and abrasion-resistant thin coating to prevent surface erosion, scratching and pitting, they could perform satisfactorily for a long time.

Plastics films are used with a metallic coating (usually aluminum) applied to the backside in second-surface mirrors of reflecting solar concentrating collectors. The metallized plastic films that have been used or tested for use in solar reflectors are based on PET, PVF, PMMA, FEP and CAB.

Other actual or potential applications of plastics in solar energy installations are as foam insulation, as piping, and as materials in the construction of collector housing, concentrator shells and supporting structures.

Aging of the plastics used in solar energy applications has been extensively studied under normal outdoor weather conditions and in artificial weathering devices. Very little information is available, however, on their short-term performance under actual service conditions, and none has been reported on their long-term durability.

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Résumé—Cet article traite de l'état des connaissances sur l'emploi des plastiques dans des applications relatives à l'énergie solaire, en insistant particulièrement sur leurs avantages et leur durabilité. L'existence de divers types et formes de matières plastiques (y compris les plaques, les pellicules et les mousses) explique la multitude d'applications courantes et possibles dans des installations à l'énergie solaire. Par conséquent, les plastiques peuvent être employés comme des vitrages, des structures alvéolaires anti-pertes et des encadrements pour les capteurs à surface de captation plane, comme surfaces réfléchissantes, lentilles optiques, enveloppes, éléments structuraux et porteurs pour les capteurs solaires à concentration, comme isolation et tuyauterie. Les matières plastiques mentionnées dans l'article en tant que composantes d'installations solaires comprennent le poly(methacrylate de methyle), le polycarbonate (PC), le polyester renforcé à la fibre de verre (PRV), le poly(fluorure de vinyle), le popolymère d'éthylène–propylène fluoriné (FEP), le poly(téréphthalate d'éthylène) (PTE) ainsi que diverses mousses plastiques.

Des études approfondies ont été faites sur le vieillissement naturel et artificiel de la plupart de ces plastiques et les résultats de ces études sont décrits brièvement. Toutefois, il y a peu de renseignements sur le performance à court terme des plastiques en tant que composants d'installations à l'énergie solaire et on ne connait rien sur leur durabilité à long terme dans une telle application.

Le niveau d'inflammabilité varie d'une matière plastique à l'autre. Il faut donc choisir des matériaux d'une résistance au feu adéquate ou de conceptions appropriées (ou les deux) pour les installations où il peut y avoir des risques d'incendie.