UDC 697.329

FUJI EVACUATED GLASS-TUBE COLLECTOR

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I. INTRODUCTION

The solar collector is the most important component in a solar heating system. The collectors used in today's heating, cooling and hot water supply systems are grouped by performance into three main types.

(1) Flat plate type collector (low temperature, selective absorber)
(2) Flat plate type (high temperature, selective absorber)
(3) Evacuated glass-tube collector (selective absorber)
Fuji Electric has developed an efficient and reliable evacuated glass-tube collector which is expected to become the favorite type in the industrial field.
The construction, specifications, features, and performances of this collector are described.

II. CONSTRUCTION

Fig. 1 is an exterior view of the collector, *Fig. 2* shows its construction. The Fuji evacuated glass-tube collector consists of a single module containing six or eight collection tubes. *Fig. 1* shows an eight tube module.

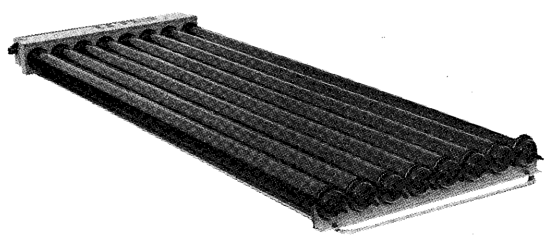


Fig. 1 External view of Fuji evacuated glass-tube collector

Fig. 2(a) shows the collection tube construction and medium flow. Selective surface absorber plates are inserted in the glass tubes. Collector tubes through which the medium passes are installed to the absorber plates. The collector tubes are double tubes consisting of an inner tube and an outer tube. The medium flows through the tubes in the direction of the arrow in the figure.

Sunlight passing through the glass tubes is absorbed by the absorber plates and its heat is absorbed from the collector tubes by the medium. The inside of the glass tubes is maintained at a low pressure of about 10^{-4}mmHg by vacuum insulation. One end of the glass-tube passes through

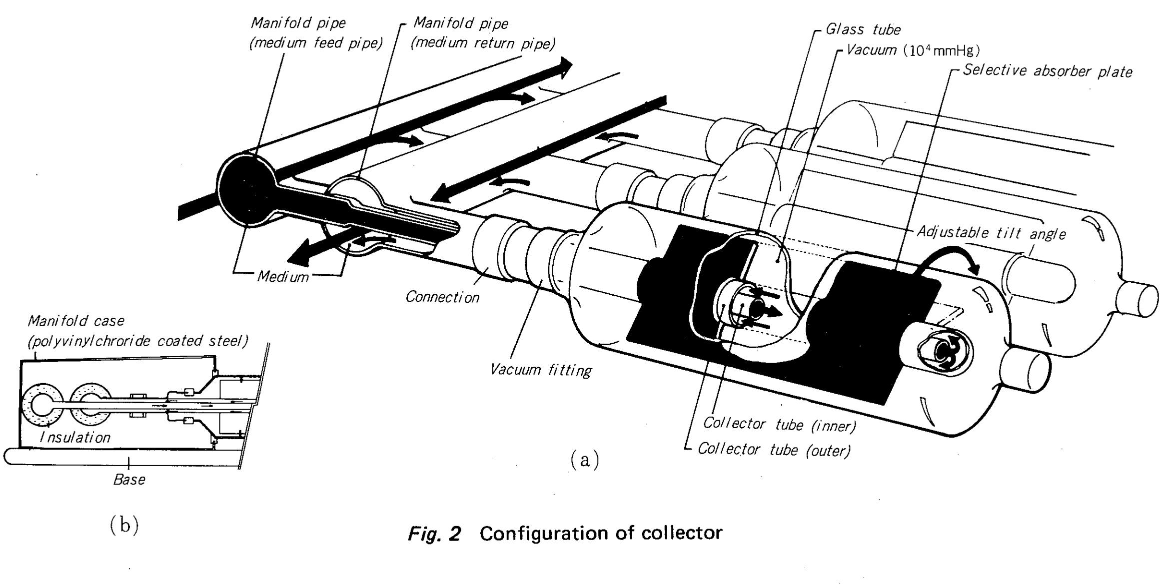


Fig. 2 Configuration of collector

the collector tube. The glass-tube and collector tube are connected through a vaccum fitting. The other end of the tube is formed into the shape of bowl and is vacuum sealed at the center.

One end of the medium outer tube is attached at the feedthrough section. However, since the other end can be freely moved in the axial direction by thermal expansion, thermal stress is no problem. The vaccum fitting is made of a special stainless steel having about the same thermal expansion coefficient as glass. The vaccum fitting and glass tube are not connected by fillet glass (low melting point powdered glass), but by a direct sealing system in which the glass is welded to the fitting for an extremely reliable glass-metal seal.

Fig. 2(b) shows the construction of the collector header. The collector itself has internal manifold pipes. Therefore, connection of separate external manifold pipes when connecting collector modules in series or parallel is unnecessry.

The medium is guided from the medium feed manifold pipe to the inner collector tubes of each absorber tube and is sent to the medium return manifold through the outer collector tube of each tube.

Six or eight absorber tubes are connected in parallel to the medium manifold pipe to form one collector module. Several of these modules can be easily connected in parallel by interconnecting the feed and return manifold pipes of each module with special connectors.

The absorber tube is connected so it rotates with the manifold and can be detached. Therefore, the tilt angle of the absorber plate can be arbitrarily set to the best angle for the system. If a tube should be damaged, it can be replaced. The inner pipe connections are sealed with wrapping and the outer pipe connections are sealed with a special rubber sealant to prevent medium leakage.

III. SPECIFICATIONS

Table 1 lists the specifications of the collector. Two models, FES6 and FES8, having a different number of glass tubes are available. The FES8 is used as standard in both heating and cooling and hot water supply systems.

Table 1 Specifications of collectors

Item		FES6	FES8
Number of glass tubes		6	8
Type		Vacuum glass-tube type, forced circulation system	
Effective heat collection area (m^2)		1.36	1.81
Outside dimensions (mm)		Length 2960 x width 1,000 x height 177	
Weight dry (kg)		56.1	67.0
Weight wet (kg)		59.0	70.4
Water capacity (including manifold) (1)		2.9	3.4
Absorber plate (tube)		Aluminum selective absorber (copper pipe)	
Performance of selective coating		Absorptivity α = 0.91 or greater Emissivity ε = 0.12 or less	
Tilt angle adjustment range		0 ~ 45°	0 ~ 15°
Material	Manifold insulation	Glass wool	
	Manifold case	Polyvinylchroride coated steel	

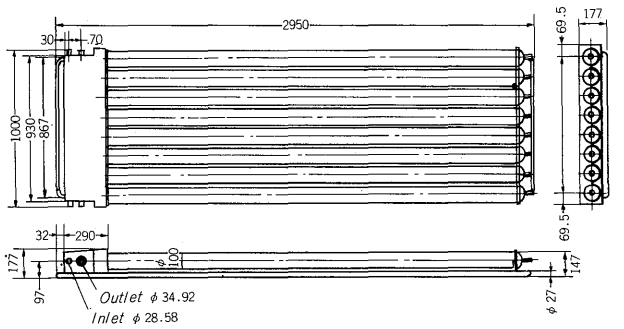


Fig. 3 External dimensions of collector

The FES6 has a larger spacing between absorber tubes than the FES8 and is used in snowy regions where the effect of snowfall is greater. Since the calorific reduction ratio of the front absorber plates is large because of the shadow produced by the rear absorber plates when the absorber plates tilt angle is large, the FES6 is applicable.

Fig. 3 shows the external dimensions of the (FES8).

IV. FEATURES

This collector has the following features. Items (1) to (3) are features compared to the flat plate type and items (4) to (7) are the features of the newly developed collector for the evacuated glass-tube type.

(1) Vacuum insulation provides high heat collection effect and high temperature collection is possible. (See *Fig. 5*.)

(2) The absorber plate tilt angle can be freely selected. The tilt angle of the absorber palte can be changed by turning the glass tube. Therefore, the collector can be installed horizontally with the roof and the large frame used with flat plate type collectors to set the tilt angle is unnecessary. (See *Fig. 4*.)

(3) Since the absorber plate is maintained in a vaccum, there is almost no selective coating change.

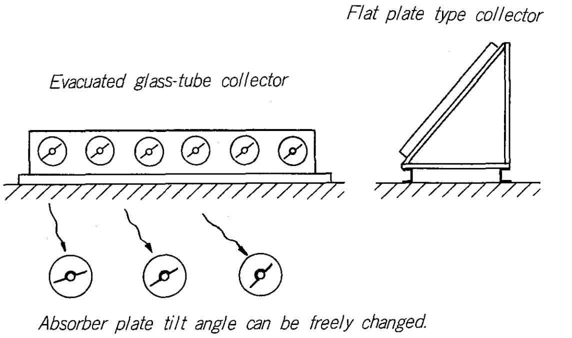


Fig. 4 Installation of evacuated glass-tube collector and flat plate type collector

(4) Little site piping.
Since the collector piping is used with the manifold piping and is internal, manifold piping is unnecessary at the site. Therefore, piping costs are lost.

(5) Little pressure drop.
Because the medium flow through each pipe inside the collector is parallel through a double pipe, there is little pressure drop. Therefore, when many collectors are installed, the pump power required is small and running costs are low.

(6) Highly reliable vacuum insulation.
The metal and glass parts are sealed at one point and a direct sealing system is employed. This system is more reliable than the fillet sealing system which is vulnerable to water and ultraviolet rays. Moreover, one side of the collector tube is free and a bellows is not employed to absorb the distortion stress caused by the different expansion amount of the metal and glass tube. This system is more reliable than a bellows system.

(7) If one of the absorber tubes should be damaged, it can be replaced singly.

V. PERFORMANCES

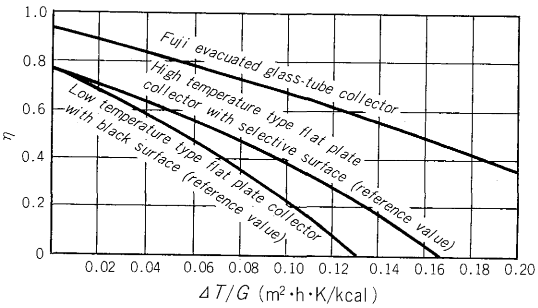
1. Collecting performance

Fig. 5 compares the collection efficiency of the (1) Fuji evacuated glass-tube collector, (2) high temperature type flat palte collector with selective surface, and (3) black low temperatue type flat plate collector.

Fig. 6 shows the annual heat collection at a constant collection temperature in the Tokyo area (true south, tilt angle 30°) calculated from the collector efficiency curves of *Fig. 5*.

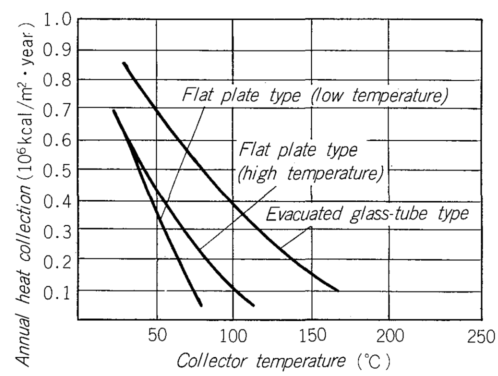
As can be seen from these figures, even the flat play type is good at temperatures below 40°C. However, the evacuated glass-tube type is good at the medium and high temperature regions about this. The evacuated glass-tube type provides a heat collection of 1.6 times that of the flat plate selective coating type at a collection temperature of 50°C and 2.4 times that of the flat plate selective coating type at a collection temperature of 80°C.

Fig. 5 shows that the evacuated glass-tube type has a maximum efficiency of nearly 1. The reason for this is that the light reflected from adjacent tubes and the random light from the rear can also be used and the actual incidence at the absorber surface is, therefore, high.



η = Heat collection/solar radiation G = solar radiation (kcal/m²/h)
ΔT = (Collector outlet water temperature + Collector inlet water temperature) /2- outside air temperature (℃)

Fig. 5 Collector efficiency



Notes) (1) *Average solar radiation* : 0.957×10⁶ (kcal/m². year)
(2) *Area* : *Tokyo, direction* : *South, Tilt angle* : 30°
(3) *Collector heat collection temperature* = (*Collector inlet temperature* + *outlet temperature*) / 2

Fig. 6 Annual heat collection

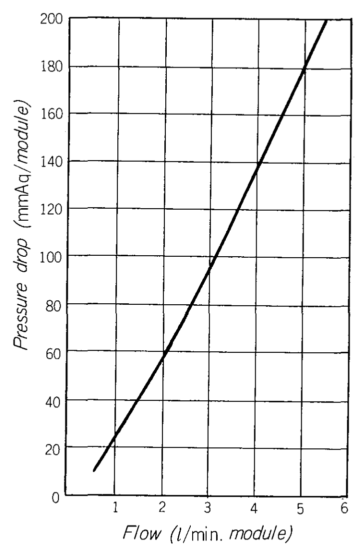


Fig. 7 Pressure drop in collector

2. Pressure drop

Fig. 7 shows the pressure drop characteristic. As can be seen from this figure, the pressure drop increases proportionally with the flow. However, since the absorber tubes are connected in parallel, the pressure drop of the collector module is extremely small and cna be virtually ignored when viewed from the standpoint of the entire system.

A standard flow of about 21/min. module so the inlet and outlet temperature difference at the maximum sunlight level becomes 10K is considered the criteria. The pressure drop at this time is about 60mmAq.

3. Performances of selective coating

To raise the efficiency of a collector, the heat dissipated from the collector must be made small. Heat dissipation is caused by radiation, convection, and conduction. Of these, convection and conduction can be significantly reduced by a vaccum insulation construction. Since radiation is proportion to the fourth power of the absolute temperature, it increases abruptly as the temperature increases and is directly proportional to the emissivity of the absorber plates.

The selective coating is a special surface processing that absorbs short wavelengths – that is, solar spectral – and radiates little long wavelengths – that is, the spectal radiated from the absorber surface. As shown in *Fig. 8*, the spectral reflectivity of the selective coating used in this collector is absorptivity $\alpha = 0.91$ or greater and emissivity $\varepsilon = 0.12$ or less.

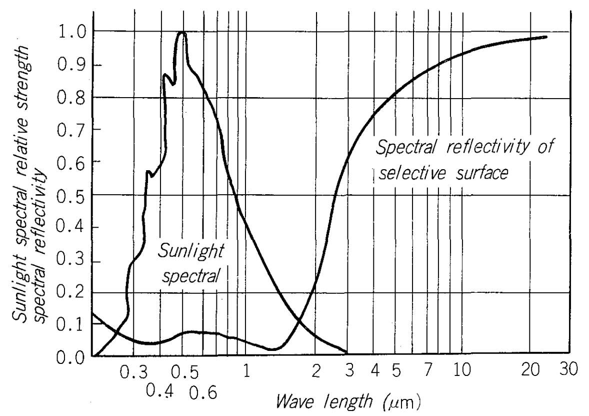


Fig. 8 Spectral reflectivity of selective surface

4. Collector strength

Table 2 summarizes the strength of the collector. A supplementary description will be given in the next item.

1) Concentrated load

The evacuated glass-tube was supported at two points and the bending strength of the tube was tested at a one-point concentrated load. Fifteen 100mm outside diameter, 2mm wall thickness, 3,000mm long glass tubes were used as the specimens. The results of the tests performed at a 2,600 two-point span were maximum shatter load 182kg, minimum shatter load 127, and standard deviation 33kg. The calculated minimum bending strength of the glass-tube was approximately $550 kg/cm^2$.

2) Shock load

A 280g steel ball dropped from a height of 50cm is equivalent to 4cm diameter hail. The specimens did not shatter during this process. The dropping position was raised and six specimens were tested. The specimens did not shatter until the dropping height reached 120-190cm. No significant differences were found within the test range for evacuated glass-tube and normaly pressure glass-tube.

3) Wind resistance

As shown in *Table 2*, the safety factor for a wind velocity of 60m/s is 4.6 and the safety factor for an installation height of 25m calculated according to the Construction Standards Law is 5.2. These safety factors were found by finding the maximum bending stress from the equally distributed wind load and subtracting the $550 kg/cm^2$ bending strength of the glass-tube measured at item 1).

(1) The equally distributed wind load Wkg/cm was calculated from the equation:

$W = C \times \frac{1}{2} \rho V^2 A$

where C: Resistance coefficient 1.0

p: Unit mass of air $0.119 kg.s^2/m^4$

A: Cross sectional area per 1cm of glass-tube $0.001 m^2$

V: Wind velocity (m/s)

(2) The wind pressure based on the Construction Standards Law was calculated from the equation:

Table 2 Mechanical strength of collector

Item	Objective	Load	Safety
Concentrated load	Single glass tube	Minimum 120kg	No shattering
Shock load	Single glass tube	280g steel ball dropped from a height of 50cm. (Equivalent to 4cm diameter hail)	No shattering
Wind resistance	Single glass tube	Construction standards Law Implementation ordinance Article 87 for an installation height of 25m for a Wind velocity of 60m/s	5.2 4.6
Snowfall	Collector	Construction Standards Law Implementation ordinance Article 87 2m snow accumulation ($2 kg/m^2$ for 1cm accumulation)	2.4
Vibration-resistance	Collector	For 810Gal acceleration	No shattering

Table 3 Earthquake level (Ref.)

Earthquake level	Designation	Contents	Acceleration
V	Strong	Cracking of walls, toppling of graves and stoves, damage to stone walls, chimneys, etc.	80 ~ 250
VI	Powerful	Collapse of 30% or less of roofs, land slides, cracking of the earth, etc. Strong enough to knock down many people.	250 ~ 400
VII	Severe	Collapse of more than 30% of roofs, land slides, cracking of the earth, faults, etc.	400 or greater

Table 4 Transmissivity change of glass tube

Wave length (nm) / Radiation time (h)	400	500	600	700
0	90.8	91.3	90.9	90.1
50 50	90.4	91.2	90.9	90.0
100	90.1	91.1	90.7	89.8
200	90.1	91.1	90.7	90.0
500	89.9	90.9	90.5	90.0
1,000	90.2	90.8	90.5	89.9

Table 5 Weather resistance of polyvinylchloride coated steel

Test item	Rated value		Test method	Test result
	Corrosion and weather resistance	General outside covering		
Exterior view	No scratches, cracks, or rough rust detrimental to use		According to 5 of JIS K 6744	No defects were found
Erichsen test	No peeling		According to 8 of JIS K 6744	No peeling
Bending test	No fractures, cracks, or peeling		According to 8.3 of JIS K 6744	
Cold resistance			According to 8.4 of JIS K 6744	No defects
Evaporated water resistance	No contraction, fracturing, cracking, wrinkling, peeling or noticeable discoloration		According to 8.5 of JIS K 6744	No defects
Chemicla resistance	No rusting, soiling or noticeable discoloration		According to 8.6 of JIS K 6744	No defects
Corrosion resistance	No rusting		According to 8.7 of JIS K 6744	No defects
Weather resistance	No rusting, cracking, or noticeable discoloration		According to 8.8 of JIS K 6744	No defects
Self-extinguishing	Extinguishes immediately		According to 8.9 of JIS K 6744	Extinguished

Wind pressure G = velocity pressure × wind pressure coefficient (kg/m^2)

Velocity pressure $q = 120\sqrt[4]{h}$ (kg/m^2)

where h: Height above ground

Wind pressure coefficient is 0.7 for a cylinder.

4) Snowfall strength

From *Table 2*, the safety factor for 2m of accumulated snow is 2.6. The accumulated snow load Wkg/cm per unit length of glass tube was calculated from the equation:

W = H. G. A

where H: Height of accumulated snow (cm)

G: Snow load per 1cm of accumulated snow $2kg/m^2$ (According to Construction Standards Law Implementation Ordiance Article 86)

A: Cross sectional area per 1cm glass tube $0.001m^2$

5) Vibration-resistance

Since the collector is subjected to vibration acceleration during earthquakes and shipment, it was tested by applying the acceleration below with a vibration tester and the absence of abnormalities was confirmed.

Vibration direction: Vertical

Vibration frequency: 860cpm

Total vibration width: 2mm

Acceleration: 810Gal (0.83G)

Table 3 lists the Metereological Agency earthquake levels for reference.

5. Water pressure resistance

The normal pressure of this collector is $5kg/cm^2$. However, at the pressure resistance test, a water pressure of $10kg/cm^2$ was applied for 10 minutes and no water leakages were found.

6. Thermal shock resistance

(1) A thermal shock resistance test was performed on the sealed parts of the glass tube when the low temperature medium was passed through the absorber tube in the burn-out state (exposure to sunlight without the medium flowing).
The burn-out state was simulated with a lamp and 5°C water was passed through the absorber tube at an absorber tube center temperature of 273°C and no abnormalities were found.

(2) The glass tube thermal shock test was performed by assuming sundown of a fair day. No damage was found at $\Delta T = T_1 - T_2 = 85°C$ when a single glass tube uniformly heated in an electric oven (temperature T_1°C) was quickly immersed in cold water (temperature T_2°C).

7. Glass tube transmissivity change

As shown in *Table 4*, there was almost no change.

8. Covering weather resistance

Table 5 shows the results of the weather resistance test when the manifold case was made of polyvinylchloride coated steel.

VI. CONCLUSION

The newly developed evacuated glass-tube collector was outlined. This collector will be used in air conditioning and hot water systems in the future.