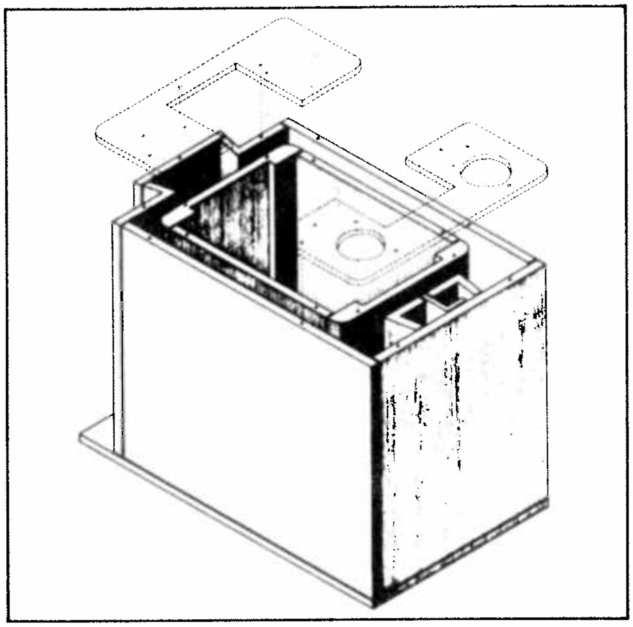
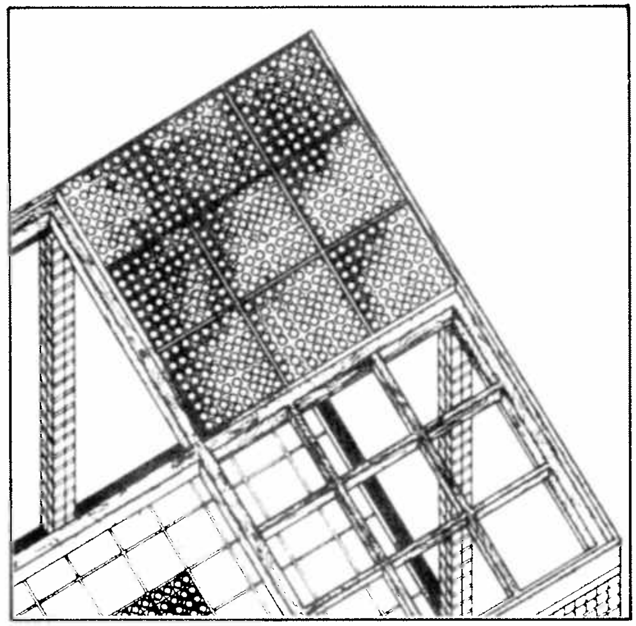
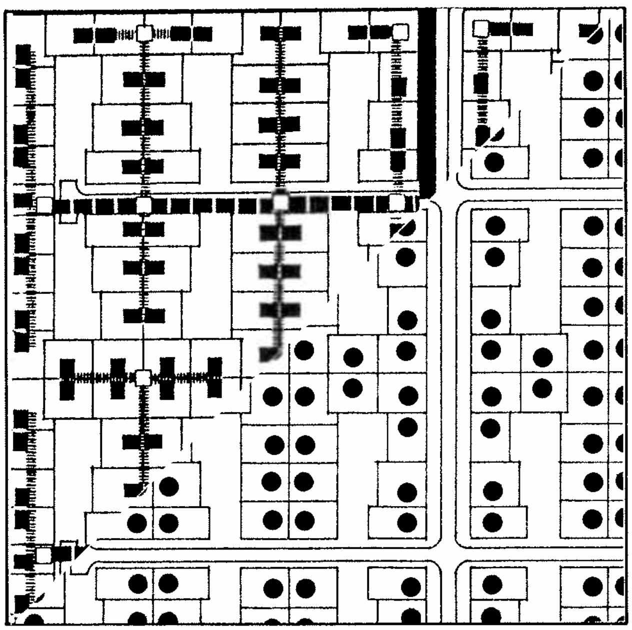
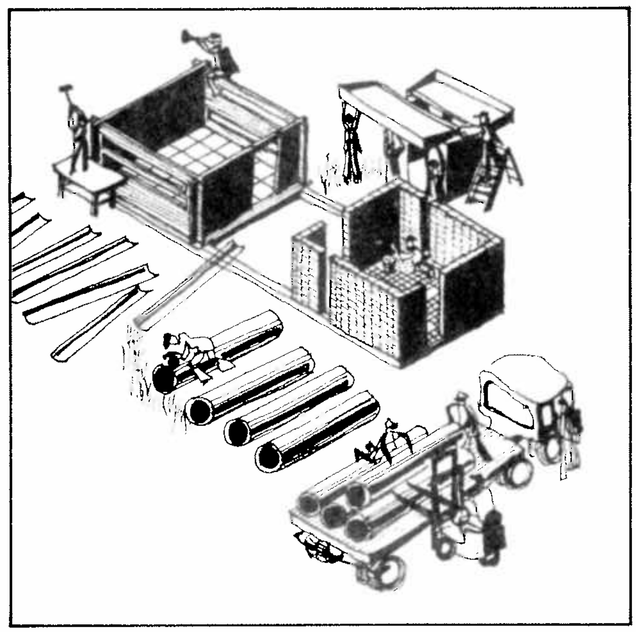

A LOW COST GARBAGE BAG SOLAR WATER HEATER

by

V.S. Nataraj, V. Bhatt

Research Paper No. 5 August 1980

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ABSTRACT

A domestic solar water heater of the "closed membrane type", combining collector and storage, has been built and tested at McGill University. The outstanding feature of this unit is its low cost, about $1, which was achieved through the use of inexpensive mass-produced dark green polyethylene envelopes, better known as garbage bags. "Off-the-shelf" hardware and "do-it-yourself" assembly techniques enable the users to assemble the water heater with the minimum amout of time, effort and money. An experimental model has been tested in Montreal during the months of July, August and September. The effects of insulation, glazing and reflectors has been studied and evaluated. The optimal solution, from a cost-benefit point of view, was found to be the plastic bag with base insulation, no glazing and no reflector. Under Canadian conditions the heater may find application in camp-sites and weekend homes during the warm season. The ubiquitous garbage bag also makes year-round application possible in tropical countries.

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INTRODUCTION

The objective of the research project described in this paper was to design and test a solar water heater whose outstanding feature was to be its low cost. It was understood that such a heater could not claim the "best" performance, nevertheless it was hoped that standards of efficiency sufficient for domestic needs could be met. The final product was intended both for less-developed countries in the tropics, and for certain applications in Canada, such as weekend homes, boats and campsites. It was intended that the unit should be simple enough to be constructed by the user himself.

A survey of solar water heater literature indicated that this "simple" technology actually comprised a number of different generic solutions, of varying complexity and sophistication, and not all by any means low cost. The most sophisticated type is the "continuous circulating" type, currently being marketted in the United States ($600-$1500). These units are industrially produced from high-performance materials; they exhibit a high degree of efficiency and durability, are usually automated, and do not lend themselves to low cost applications. The "thermo-syphoning" type has frequently been cited as an appropriate model for "do-it-yourself" applications since it does not require pumps or automatic controls and is hence easier to build. Nevertheless, experience has shown that the cost is still relatively high. The ECOTOPE design (1) uses durable materials such as copper and could be expected to have a fairly long life, but the cost for materials alone is reported to be between $200 and $250. One of the least expensive thermo-syphoning solar water heaters has been proposed by the Brace Research Institute (2), however, material cost is estimated to be about $80 (1979) and the use of materials such as galvanized metal for the collector place limits the useful life to approximately 5 years, making this an expensive investment indeed. It seems most probable that the "batch" type solar water heaters have the best chance for cost reduction since they consist essentially of only a water reservoir within which a fixed quantity of water is heated. The reduction in complexity is, of course, accompanied by a reduction in convenience: hot water is available only by mid-day, and water cannot normally be stored for an extended period of time in the evening.

The development of batch type solar water heaters has taken place over a number of years in various countries, including Japan (3) and India (4) and it appears that material costs are generally less than $50. It was decided that the batch type represented the most appropriate solution for a minimum cost solar water heater.

The following design criteria were established:

1. The single most important criteria was to be cost; all efforts were to be directed at minimizing this factor.
2. Cost should include materials and labour in the event that the unit would be commercially produced.
3. The method of construction should minimize both special tools and special skills.
4. The heater should be able to provide at least 100 litres of hot water at 40°C.
5. The unit should not require "tracking" during the day, though seasonal adjustment would be permitted.
6. "Plumbing" should be minimal.
7. The cost of materials should not exceed $25, and the life of the unit should be 5-10 years.
8. Nightime storage of hot water is not mandatory.
9. Manual operations should not take place more than once or twice a day. The unit should incorporate some measure of "convience" rather than of "work".
10. The unit was to be designed primarily for tropical climates and hence did not have to be protected against freezing.

DESIGN PROCESS

The problem of designing an inexpensive batch type heater lies in finding a solution to the reservoir. The reservoir can be a steel cylindrical tank, a flat steel box, an open reservoir with a transparent cover plate, a closed reservoir with a cover plate, or a plastic bag (sometimes referred to as a "pillow" type). The most effective batch heater is one which reduces the water depth to about 10 cm. This is normally done by fabricating a special steel tank to these specifications, or by using a number of small diameter tanks side-by-side.

One of the most attractive solutions is the "pillow" type, which has been developed, and marketted, in Japan (3). The membrane can be opaque or transparent, thus combining absorber and cover plate in one unit, and plastics technology is sufficiently advanced, and widespread, to make this a widely available assembly technique. After some abortive attempts at fabricating battery arrays using soft drink cans it was decided to concentrate on the pillow type design.

The nucleus of this design is a common plastic garbage bag. The material is 1.6 mil polyethylene, sealed to form a bag 76 cm. x 1.22 m. The plastic is opaque (black or dark green) making an ideal absorber. It is well known that polyethylene degrades in sunlight and has a useful life of approximately 12 months. The colour of the garbage bag is achieved by the addition of carbon, which also acts as an effective filter of ultra-violet rays, thus effectively prolonging the life of the material. Finally, the cost per bag is $0.28. Since the capacity of a single bag (with a water depth of 10.0 cm.) is about 100 liters, the cost of the reservoir for the required capacity would be 28 cents.

Two problems remained. How to develop a process for sealing the bag, and strongly enough to withstand the pressure of the 50 liters of water. And, how to incorporate a plumbing fixture that would serve as inlet and drain, without affecting the integrity of the bag.

A number of sealing methods were attempted. No successful adhesives for polyethylene were identified. Industrial methods for sealing polyethylene use a combination of carefully controlled pressure and heat; the machines for this are relatively expensive, and though accessible to a small manufacturer are not easily procured by the layman. The use of a domestic flat iron proved problematic; the 1.6 mil plastic tended to melt on the one hand, or not bond sufficiently on the other. The application of a pre-heated rod along the seam had the same effect, and heat was more difficult to control. The ultimate solution proved to be one of almost staggering simplicity: it involved holding a lighted cigarette adjacent to the folded edge of the bag. The tip of the cigarette was touched along successive points, and as the plastic began to melt the edge was pressed between the thumb and forefinger. With a little practice it was possible to make 100% leakproof joints. Whether or not the operator actually smoked the cigarette was, of course, optional.

The drain/outlet was fixed to the bag by mechanical means, since, as has already been mentioned, both solvents and adhesives proved to be unsuccessful. PVC pipe, washers and nuts hold the fitting to the plastic (see Illustration 1) and polyethylene gaskets effect a tight seal. No sealants were used. The drain/outlet is inserted into the bag before the end is sealed, thus permitting tightening of the inside nut.

A completed unit was tested to failure. Whereas a bag "inflated" with water to a depth of 7.5 cm. contains about 50 liters of water, more than 100 liters were pumped into the bag which expanded to a height of 25 cm. At this point failure occured, but neither in the joints (ours and Union Carbide's) nor at the drain/outlet fitting. Failure occured within the material itself, at the apex of the "bladder" due to the stretching action of the water pressure.

This test indicates that a safe margin of safety is present in the assembly as far as water pressure is concerned, and that the techniques evolved for sealing the bag and locating the fitting were satisfactory.

PERFORMANCE

The purpose of the test was to assess the performance of the garbage bag solar water heater, and to evaluate the effect of reflectors, transparent covers and insulation on this performance with a view to identifying the most cost-effective combination. The test rig comprised a 60 cm. x 60 cm. bag filled to a depth of 7.5 cm. (about 30 liters), laid on a piece of rigid insulation (2.5 cm. thick).

Four configurations were tested:

I. Exposed bag.
II. Bag placed in insulated box.
III. Bag placed in insulated box with single glass cover.
IV. Bag placed in insulated box with single glass cover and aluminium foil reflector.

The tests were conducted on clear sunny days in July, August and September 1978. The test rig was located on a roof free from shade. Temperature of the water measured at hourly intervals between 9.00 hrs and 16.00 hrs. The temperature recorded was taken by draining water from the bag. Values for insolation or incident solar radiation were recorded at a weather station 5 km. from the test site.

RESULTS

The results of the tests are summarized in Tables I and II.

The details are not presented here though they do appear elsewhere (5) since high performance efficiency was not achieved, nor hoped for in such a low cost and technologically primitive device. The results are also to be expected: there is an increase in the rate of heating and in the absolute temperature reached as insulation and a transparent cover are added. The efficiency (heat absorbed by water vs. energy falling on the surface of the bag) likewise increases from about 30% to as high as 50%.

During the summer test period all the configurations passed the design temperature of 40°C. Hence the provision of a cover, insulation or a reflector is unnecessary, and adds a considerable cost to the otherwise inexpensive assembly. It should also be noted that the reflector had a tendency to create "hot spots" which frequently damaged the polyethylene. No damage was observed when the bag was used exposed or with a glass cover.

However, during the fall (early September) the glass cover proved necessary as the open bag was unable to achieve temperatures higher than 25°- 35°C. The glass cover was also seen to play an important role in retarding heat loss in the fall afternoons.

To summarize, the overall performance during the summer months was found to be satisfactory; the average daily efficiency of the bag alone being between 35%-40%. The water temperature exceeded 40°C., the target. The collector was able to deliver 80 liters/m^2/day of hot water on a Montreal summer day (isolation: 500-700 langleys).

CONCLUSIONS

It is possible to construct an extremely cheap water heater for as little as $1.48 (see table III) that will provide 100 liters of water at at least 40°C. Techniques have been evolved for fabricating a pillow type reservoir by modifying a standard polyethylene plastic garbage bag. On the basis of experiments it is felt that the most cost-effective configuration for such a pillow type solar water heater is that of an exposed bag on an insulated base, without side insulation, transparent cover or reflector. This experiment has not determined the exact life of the polyethylene bag.

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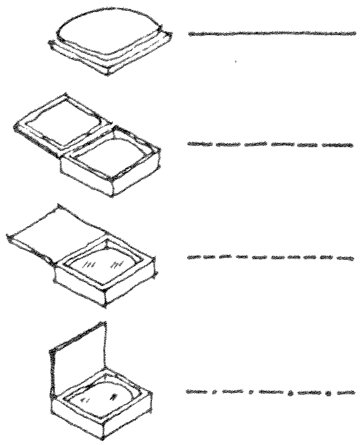
TABLE I

Comparative Performance of Different Configurations



I. Exposed bag

II. Exposed bag in insulated box

III. Bag in insulated box with single glass cover

IV. Bag in insulated box with single glass cover and aluminum foil reflector.

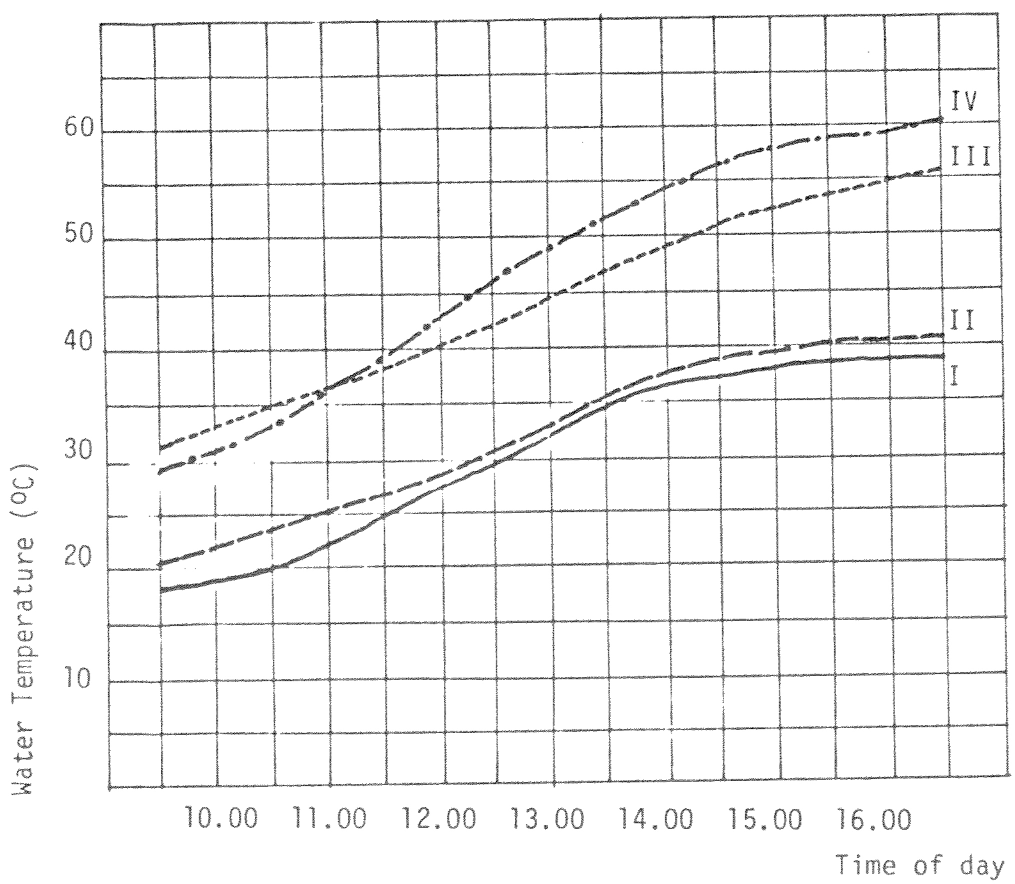
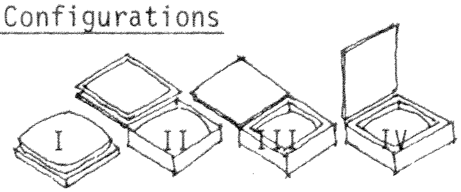


TABLE II

Comparative Performance of Different Configurations



		I	II	III	IV
Area of collector*	cm^2.	3906	3600	3186	3186
Date	-	25/8	22/8	11/8	15/8
Total insolation during 24 hour period	langleys	508	590	634	549
Average ambient air temperature during test	^oC	19.1	24.2	25.0	30.1
Water temperature (initial)	^oC	19.1	21.5	33.1	31.3
Water temperature (final)	^oC	37.7	40.3	54.3	59.9
Temperature rise	^oC	18.6	18.8	21.2	28.6
Heat collected by water	k.cals.	558	564	636	858
Energy falling on bag	k.cals.	1426	1426	1319	1166
Average overall efficiency	%	39.1	39.5	48.2	73.5

* The inconsistency in area is due to the fact that the unrestrained bag tends to spread somewhat, and the frame of the glass cover reduces the exposed surface of the bag to 3186 cm^2.

DO-IT-YOURSELF "GARBAGE BAG" SOLAR WATER HEATER

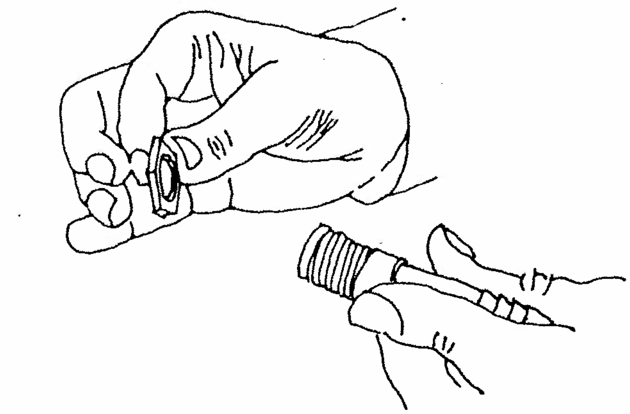
The first step is to assemble the inlet/drain fixture, the second is to fix the fixture securely to the bag, and the final step is to seal the open end of the bag. It is important that the inlet/drain fixture is fitted before sealing the bag, as it permits tightening of the inside nut (steps 5 and 6). A list of the required materials and parts has been provided, and the method of installation has also been discussed.

While calculating the cost of the unit, the cost of the collector and insulation have been considered; the cost of providing a base or stand has not been included, as these would depend on the particular circumstances or situations where the installation is to be made. The cost of the stand or platform to support the bag will certainly be much higher than the cost of the collector alone, but will last much longer (i.e. over ten years). The low-cost garbage bag collector will have to be replaced periodically as it is made of low-performance materials (i.e. every 12 months or so, depending on the condition of the bag).

TABLE III

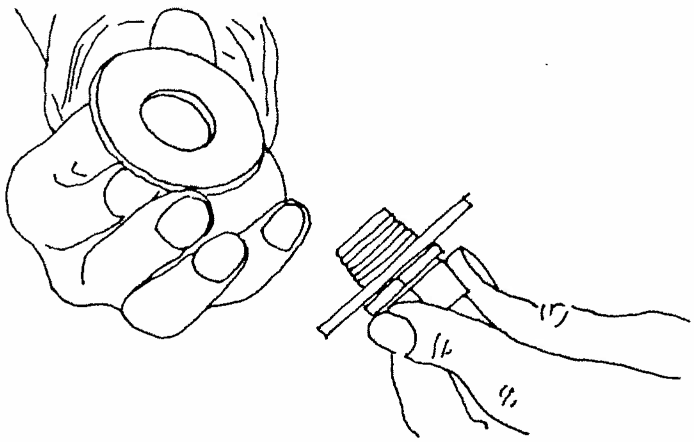
Cost for One 100 Litre Unit (1978)

Large Polyethylene Garbage Bag (1)	$0.28
Hex Nut (2)	0.20
Washer (2)	0.14
PVC Pine (1)	0.14
Rigid Insulation Base (1- 130cm x 90cm)	0.72
Total	$1.48



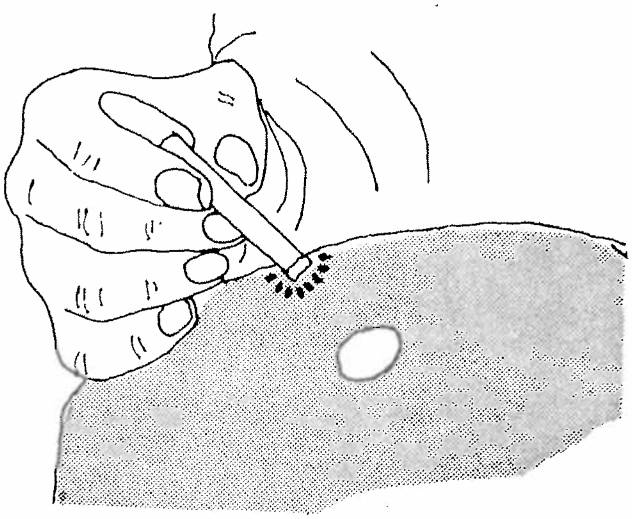
Step 1

Thread the hexagonal nut to the PVC pipe and tighten.



Step 2

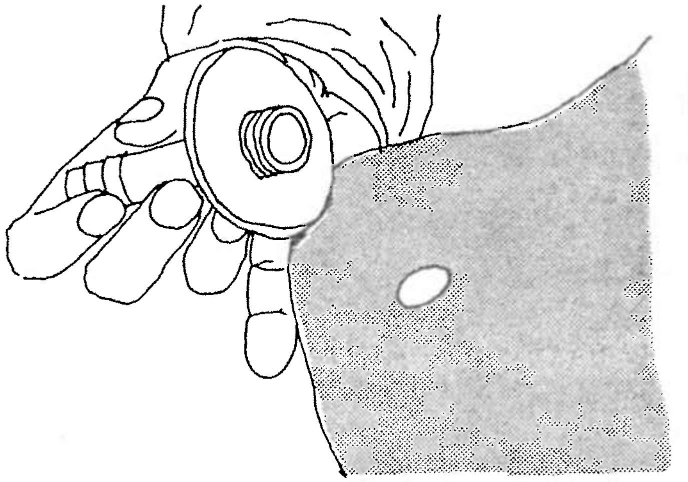
Insert the washer first, an then the gasket.



Step 3

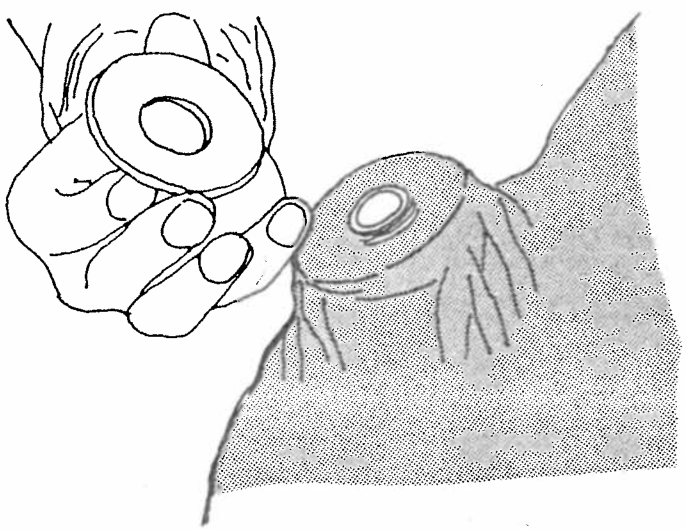
Make a hole (2cm diameter) in the center of the bag with a lighted cigarette.

Take care to make the hole on only one layer of the bag.



Step 4.

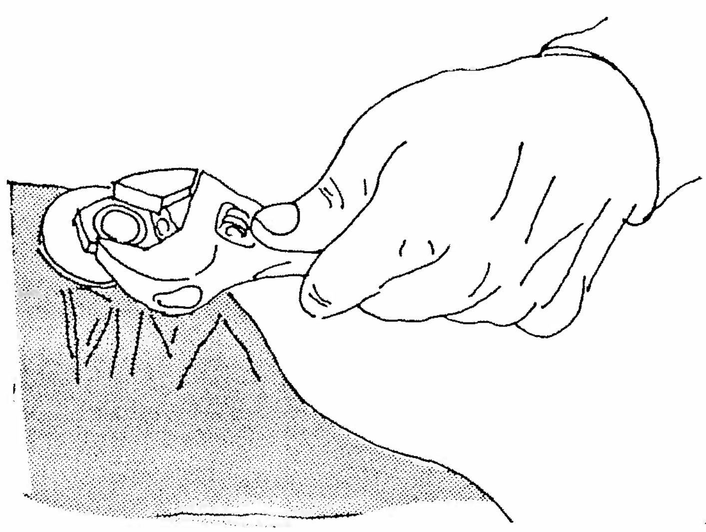
Insert PVC pipe, fitted with washer and gasket, into the hole made in the skin of the bag.



Step 5

Invert the bag and insert another set of gasket and washer.

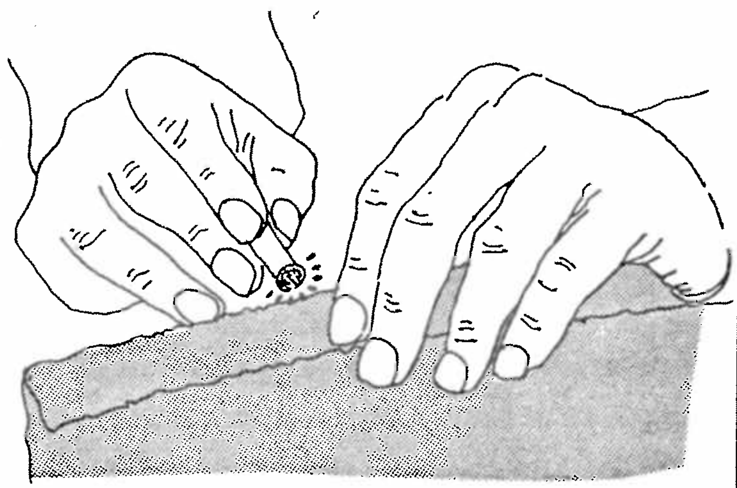
The bag is inverted so as to permit tightening of the inside nut.



Step 6

Thread the hexagonal nut to the pipe and tighten with wrench.

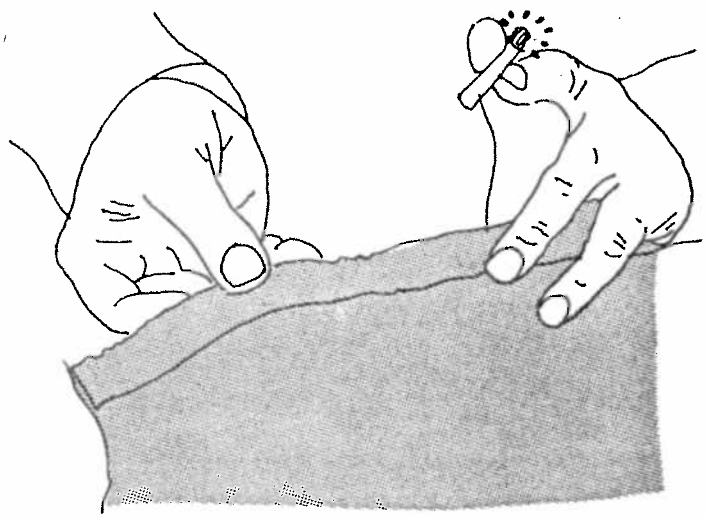
The inlet/drain fixture is now fixed.



Step 7

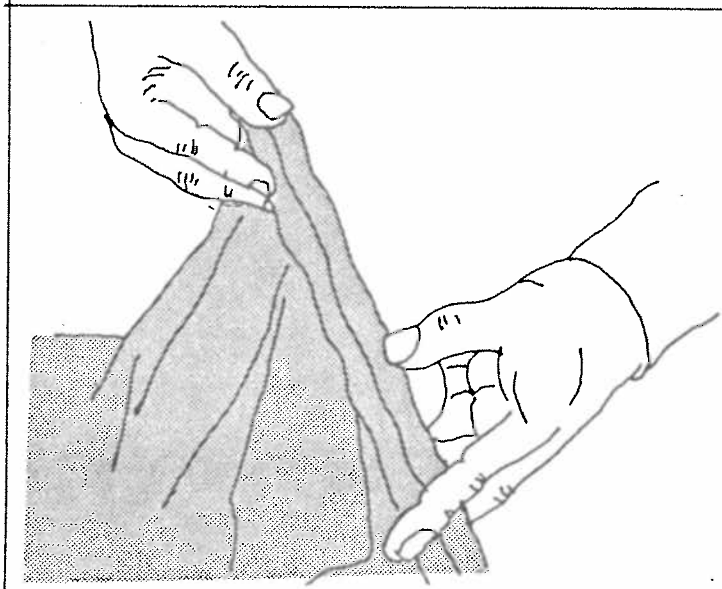
Lay the bag flat and fold the edge to be sealed.

Hold a lighted cigarette adjacent to the edge, touching at successive points.



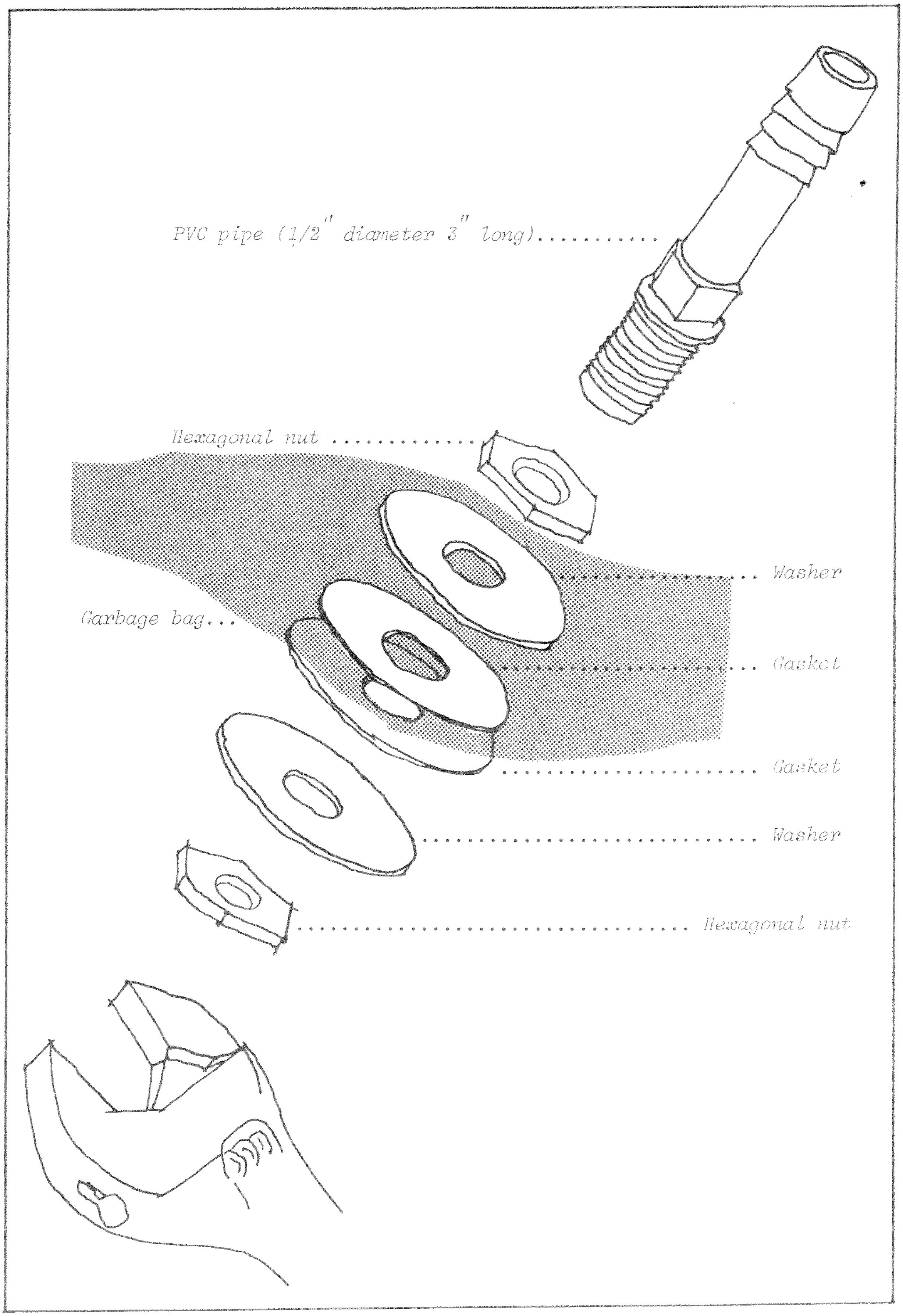
Step 8

As the cigarette is touched, the polyethylene will start to melt: Press the edge between thumb and forefinger.



Step 9

Fold open the sealed edge and check for gaps. Make corrections, if necessary.


PVC pipe (1/2" diameter 3" long)
Hexagonal nut
Washer
Garbage bag
Gasket
Gasket
Washer
Hexagonal nut