DEVELOPMENT OF SPECIALISED CROSS-AND TRANSVERSE-FLOW CAPILLARY MEMBRANE MODULES

Final Report to the

Water Research Commission

by

SE Domröse, RD Sanderson and EP Jacobs

Institute for Polymer Science, University of Stellenbosch
Private Bag X1, Matieland, 7600

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EXECUTIVE SUMMARY

INTRODUCTION

Transverse-flow membrane modules are required for many research, laboratory, commercial and industrial applications, because of their higher mass-transfer coefficients (than the axial modules), modular design, individual stacking freedom and future possible uses as bioreactors.

Excellent progress has been made to date in the development of the new modules. The modular transverse flow module is small in size, very adaptable and therefore easy to transport, install and operate. These factors make it accessible to institutions, training centres, technicons and universities for collaborative research efforts.

A social consciousness and awareness of the ever-increasing demand for potable water and its diminishing supply motivates us to make full use of science and technology to develop and produce devices with which to recycle and purify water, to potable and industrially usable standards, at the lowest possible cost and in the most energy-efficient way.

In 1996 over 50 million people died from infectious diseases. According to the World Health Organization this was mostly due to a lack of clean potable water, bad sanitation and also failing to administer oral re-hydration solutions in cases of diarrhoea.

OBJECTIVES

The main objective of this project was the development of a transverse flow capillary membrane module housing more than 10 capillaries per template, built in a modular system consisting of stacks several layers high.

MODULE FUNCTIONS

There are numerous possible ways, presently envisaged, in which a module can be used. It is, however, only by pilot plant studies that the feasibilities of the various possibilities can be explored. At present we only have feedback on the successful applications of the laboratory-type module in the laboratories of Rhodes and Stellenbosch Universities.

The following points outline the working principles of the modules:

1] A liquid feed stream enters the module through one of 4 smaller feed channels. The permeate and concentrate are kept separate, in the case of internally-skinned capillary membranes, while in the case of externally-skinned membranes the feed would enter through a main inlet port and the concentrate would exit from one of four secondary feed channels.

2] A liquid feed stream enters the module. A gas or secondary feed can be added to the feed stream or stripped from the feed stream, resulting, for instance, in a gas-enriched or gas-stripped liquid product.

3] The module is capable of being used as a bio-reactor.

4] The module can be used in any combination of the above three (or more) possibilities, either by feeding from the top or from the bottom (depending on the application).

In all the above cases it is essential that complete and reliable sealing between the various channels, and also of the module as a unit, is achieved.

MODULE DESIGN

Emphasis was placed on designing a reliable, robust and chemically-resistant module, suitable for mass production in a modular system. Scope for freedom of stacking, use of various capillary membrane types, the number of layers in a stack and/or the number of stacks or blocks in a module is required. It should be possible to make a choice of internal or externally-skinned capillaries. Careful attention to detail had to be given to the locating, anchoring, support and protection of the membranes. The materials to be used in the construction of the module must fulfill the functional aspects of the module; these include being sterilizable and capable of meeting the manufacturing requirements.

RESEARCH RESULTS

Highlights of the research results achieved included the following:

1. A locating spacer frame, which fully locates and encloses the capillaries, has been successfully designed This spacer frame prevents encapsulating material blocking capillary membrane surface areas, and also provides a support lattice which counteracts the forces generated by the product feed stream.

2. The module was designed in such a way as to ensure hydraulic sealing of all the flow channels.

3. The designs of the inlet and outlet manifolds were such that they ensured that the feed did not dislodge or damage the membranes. The feed was distributed over the entire membrane area.

4. A modular model was designed in such a way which made possible the successful incorporation of an infinite number of geometrical and application combinations.

5. A manufacturing method was established which included the bonding of a spacer frame and encapsulation with silicon rubbers of different shore (A) hardnesses, viscosities and densities. This has never before been achieved in the silicone field.

6. A low-cost silicon-rubber casting plunger-type mould was developed for the spacer locating frame. This is suitable for Cottage Industries as no electricity is required and the clamping forces are generated by a number of tightening bolts. The cost of this mould is only one tenth of that of a conventional multi-gate, hot-runner, core-pulling mould.

7. A reliable and novel encapsulation method was developed which prevents leakage between the templates. The overhanging transverse frames, once encapsulated, are interlocked into a tight structure. This is because the silicon rubber is able to be dispersed between the overhanging layers of the templates and not only on the outsides. This provides more available surface area for bonding and produces a stronger structure. (This is illustrated by the knuckle idea - the encapsulating material "goes around" all the templates and flow channels, thereby sealing them off completely.)

8. Modules were developed which are chemically resistant to many solvents, as silicon resin is used. This makes them suitable for the use in food and drug applications and the purification of harsh effluents and liquids.

9. Industrial-size transverse-flow capillary membrane modules of membrane areas $17m^2$ and $24m^2$, of 1 m height, consisting of 333 template layers in the cases of the internally and externally skinned capillaries, were developed. Furthermore, these individual modules can be connected in series or parallel arrangements to form large units of 100 m^2 of membrane area or more.

10. The areas of very large modules with 200 capillary membranes per layer, 333 layers high (1 meter high) would be $186m^2$ and $250m^2$ for internally and

externally skinned membranes respectively, can be constructed using the same methods as those used for the present model.

11. The silicon rubber spacer frames and the cured encapsulation resin can be used in temperature applications in excess of 200°C.

CONCLUSION

Research results and products have exceeded the original objectives of this project. The membrane area has been increased 40 fold over that of the laboratory-type transverse-flow module.

RECOMMENDATIONS

A pilot or field study project should be initiated to fully explore possible applications of this module. These would be for water purification, recycling, the treatment of effluent and industrial applications for food processing, breweries, carbonation of mineral water, pharmaceutical and electronic processes and bio-leaching. For such purposes more modules and pilot plants will be required.

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Proto Vervaardigers for making the mould for the locating template frame.

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1 INTRODUCTION

A detailed account of the research and development carried out during the period from the 1st January to 31st Dec. 1997 on the Water Research Commission contract K 5/847 "Development of Transverse Flow Capillary Membrane Modules of the Modular and Block Types for Liquid Separation and Bio-reactors," for use in water treatment for rural and industrial use is given here. During the previous research projects K5/387 ('91 to '93) and K5/618 ('94 to '96) the following was undertaken : The development of a lab size module with 10 capillary membranes, and preliminary design work towards the creation of an industrial- size module.

In order too align capillary membranes in a transverse-flow capillary membrane model, some structure with a linear anchoring system for the capillaries had to be devised. A model making use of cylindrical holes interspaced along the lengths of a template was developed and its manufacturing details were investigated. It was ascertained that to mass-produce such an item by injection moulding involved the tooling of an intricate mould consisting of multi-gate hot runner systems with a built-in core pulling device, which would be necessary in order to eject the component after cooling. A material such as Nylon 6 would be used for the template. Such a mould would cost in the region of R200 000 and, although this would be the route to take once the final product was ready for mass production, it was not viable on our present research budget, especially as the mould would probably have required modifications during our development period.

Changing the design of the template from cylindrical holes to wrap-around undercuts, resulted in there no longer being the need for a core pulling device, provided that the material used had elastomeric properties to enable the undercuts to be ejected. Silicon was chosen for flowability and chemical inertness.

2 TEMPLATE DESIGN

Design requirements

The main requirements of the template are to locate the capillaries in an ordered grid system and to support the capillaries to prevent dislodging during the operation of the device. A silicon rubber-wrap around system was developed, which enclosed the capillary by ± 90%, thus securing it in the template. The design also required runners, which were tapered in order to ensure that the moulding could be removed from the mould. Situated on the top of the template are locating pins which locate with the holes situated at the bottom of the template. These pins enable the spacer templates to be correctly positioned on top of each other(see figs 1 & 2)

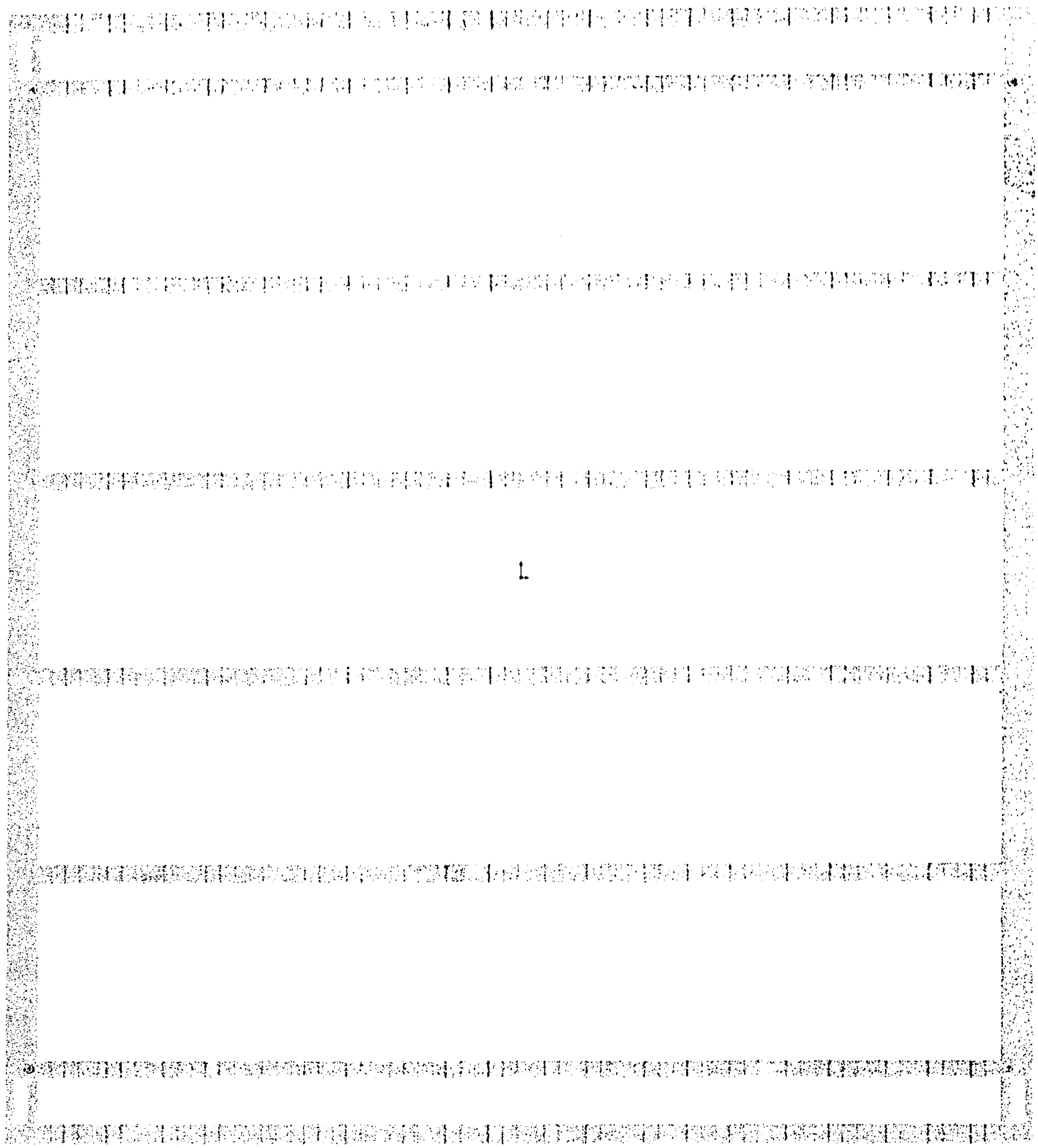


FIG 1: Top view of the spacer template showing the support structure

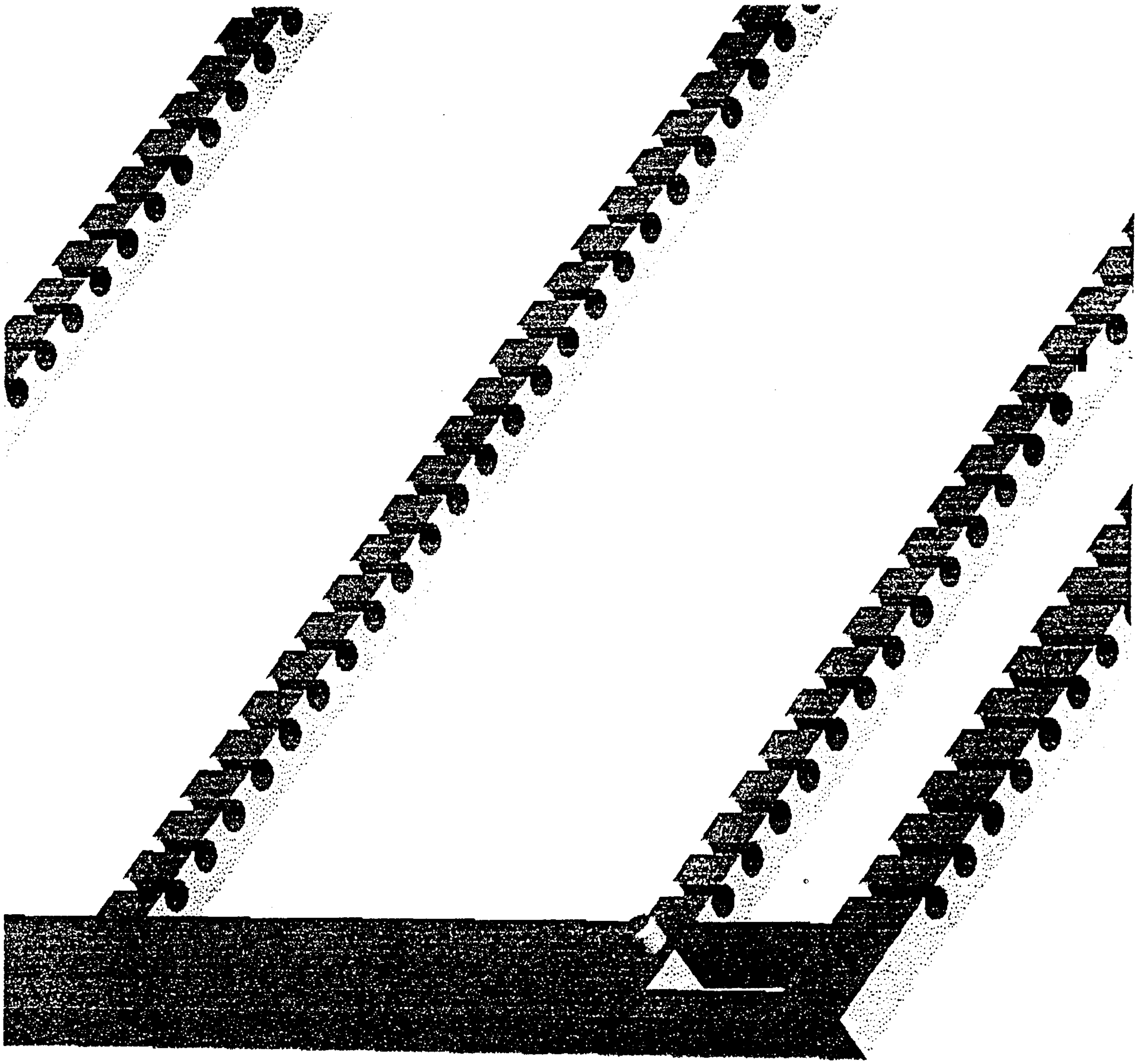


FIG 2: Spacer template showing the wrap-around locating grooves, lattice support and locating pins

3 TEST MOULDS

Test Mould in aluminum

An aluminum test mould was developed to ascertain whether or not aluminum would be a suitable medium from which to construct the spacer mould. It consisted of two aluminum rectangular bars into which 20 locating grooves were spark-wire cut forming the mould profile (see fig 3). The mould was tested to establish whether the template moulding would be able to be removed from it without breaking. This was unsuccessful as the aluminum surface was too rough and difficult to polish, as the intricate undercutting sections were damaged during this procedure. The force required to remove the moulding was too high and an alternative material had to be found.

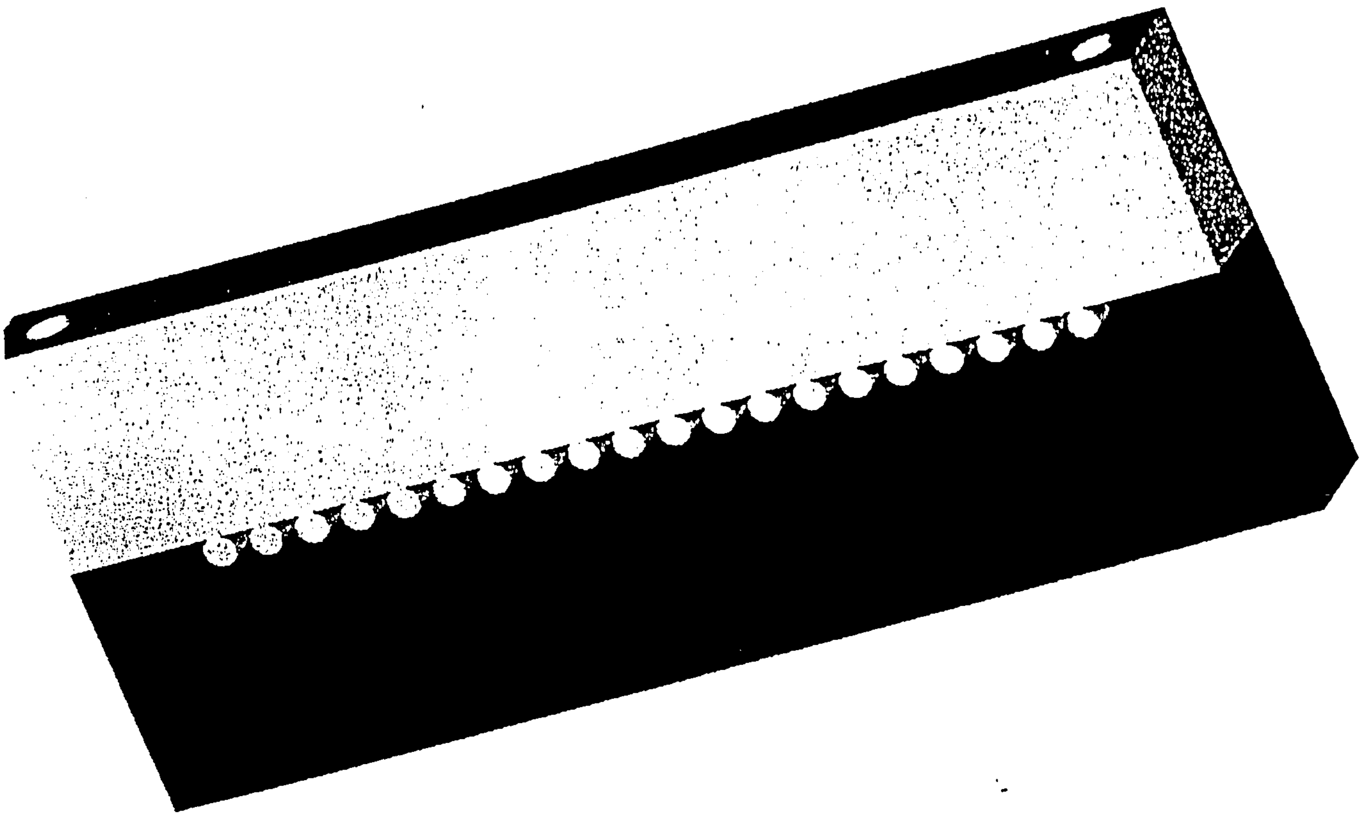


FIG 3 : The aluminium test mould

Test Mould in Teflon

Teflon has a very low surface tension and thus a very low coefficient of friction. This property should allow the moulding to be easily removed without damaging the intricate undercuts or tearing the molding. After a number of successful tests it was decided that this was the material to be used. The Teflon test mould for a spacer frame section was developed.

4 SPACER-TEMPLATE-FRAME CASTING-MOULD

We needed to move away from the expensive injection moulding multi-gate hot runner system to a more affordable plunger type mould. A hand plunger was designed using a Teflon sleeve encased in a stainless steel cylinder which was bolted onto the top half of the mould plate (see fig 4). We later changed this sleeve to one of high density polyethylene (HDPE), because we found that the Teflon thread on the base of the sleeve was being stripped and thus when we wanted to increase the diameter of the nossle at a later date there was not enough area with which to do so. The cavity plates were also machined from Teflon because of its ability to release the moulding and its chemical inertness. These plates were bolted onto the top and bottom steel mould plates (see fig 5). The whole mould was clamped together by a series of 60mm long tensile steel bolts and a torque wrench was used to tighten them, keeping control of the clamping force. The mould could also be designed and manufactured in such a way that it operated as a multi layered stack mould to improve productivity (ie. more than one spacer frame per casting from a single mould).

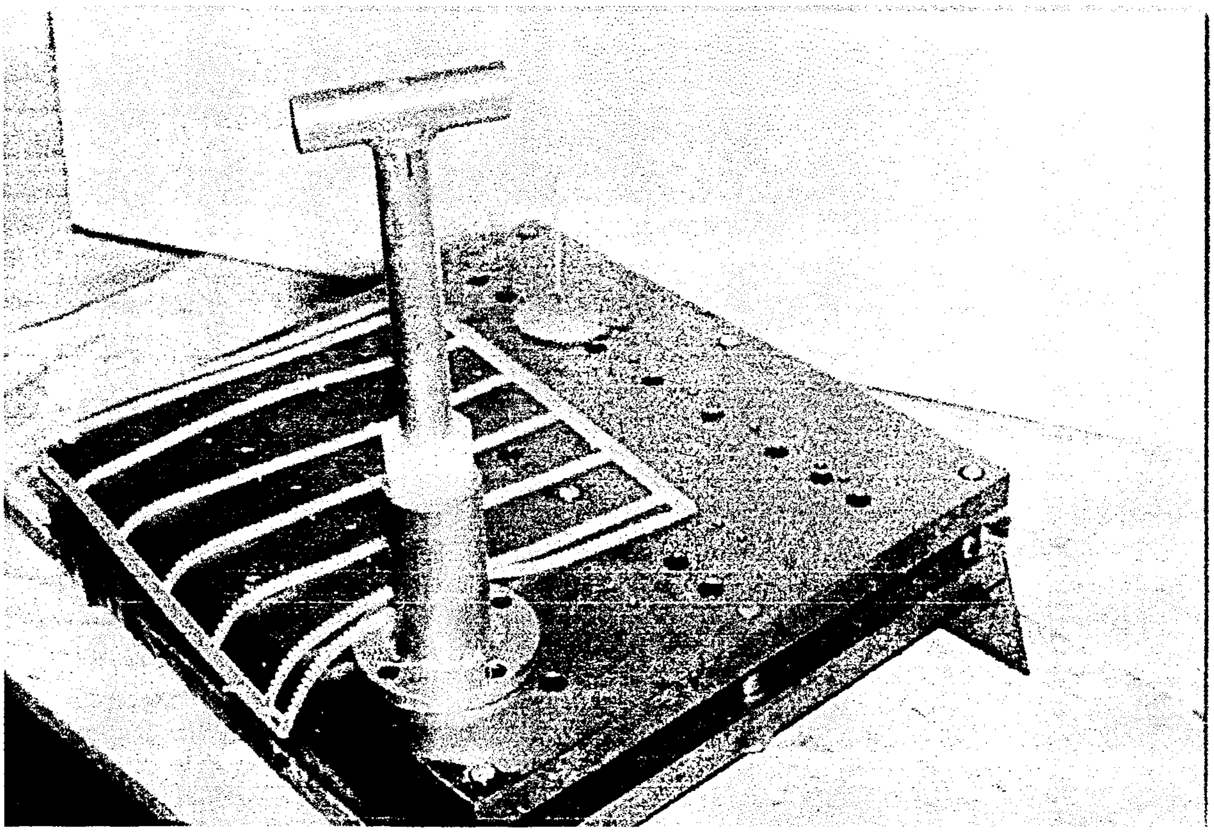


FIG 4 : Casting mould for silicon spacer frame, showing injection plunger

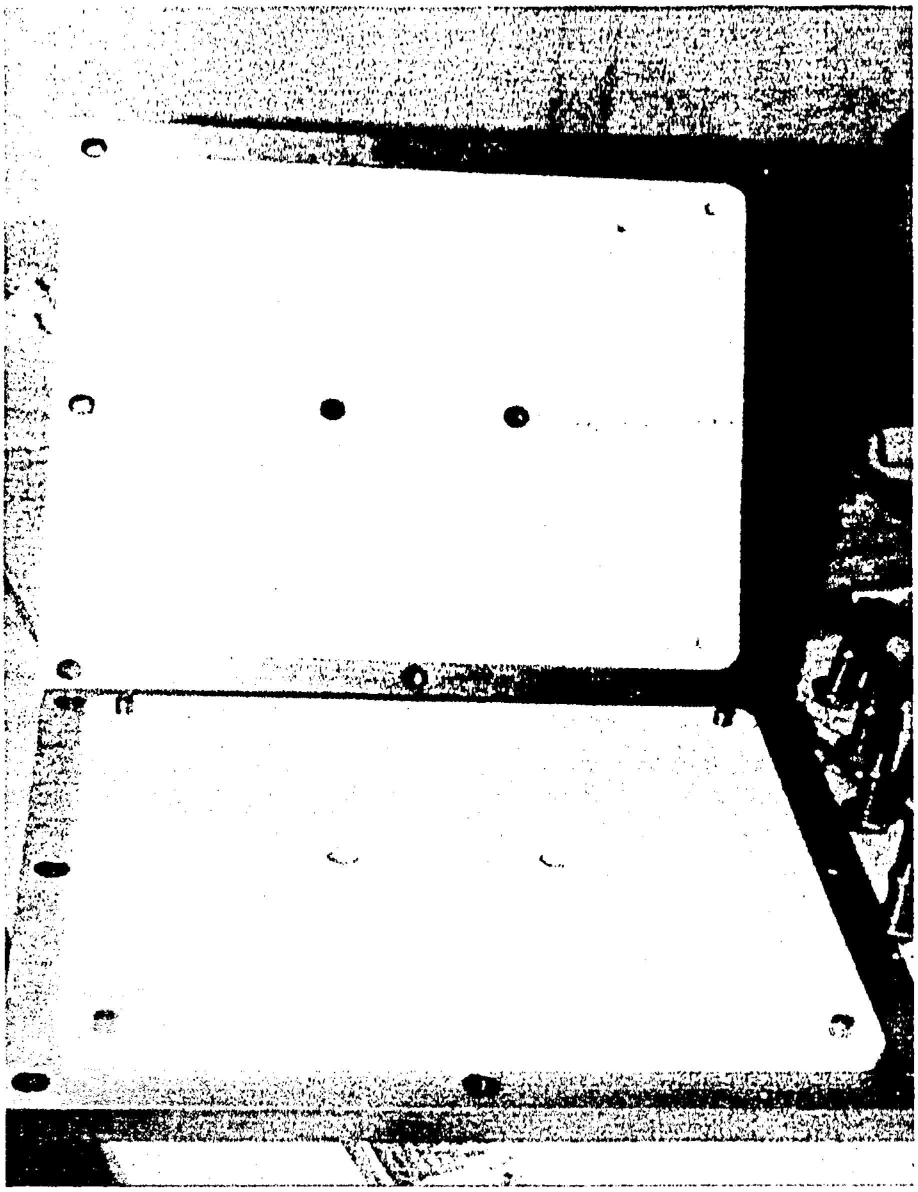


FIG 5: Silicon rubber casting mould in the open position, showing contours and clamping holes

5 SILICON RUBBER SELECTION AND EVALUATION AS A SPACER

Required Material Properties:

The template moulding requires a material which can be moulded with as little pressure as possible as our mould makes use of a hand plunger and intricate undercuts. The nature of the undercuts means that the material must be flexible enough and have a long enough elongation-to-break, to facilitate its easy removal from the mould without breakage. We were looking for a low viscosity, medium hardness material which would have the ability to bond with the encapsulating material. Four different materials were investigated viz. General Electric (G.E.) RTV 428, Dow Corning Silastic T1, General Electric YE 5626, Wacker Elastosil M4640.

1 General Electric (G.E.) RTV 428

Properties :

Cure : Condensation	Colour : Off white	Mix : 20:1
Viscosity : 30000cp	Hardness : 27 (Shore A)	Cure time : 24h

Results :

The G.E. RTV 428 was the first resin evaluated. It was easy to mix and vent by manual stirring in a paper cup, using a venturi nozzle. However, it produced a moulding which was too soft. A jig was constructed from Poly(methylmethacrylate) (PMMA) to straighten out the flexible silicon rubber spacer frame and also to enable the capillaries to be inserted into the template. For this reason a method had yet to be devised to increase the rigidity of the moulding. Glass beads were used, but the viscosity increased so much, even at a concentration of 5%, that the mix became unmanageable with our low pressure equipment. The use of talc gave us a resin with a manageable viscosity at high loadings of 35%, but a maximum loading of 25% was preferable as beyond this the moulding became brittle. It was also difficult to completely dry the talc, thus giving a certain degree of moisture inhibition.

Using a talc filler concentration of 20% (by mass) in the silicon rubber a moulding of significantly higher hardness and better dimensional stability than the unfilled mix was obtained. It was also found that by increasing the amount of curing catalyst the curing time could be reduced to 8h for a mix ratio of 10:1.

It was unfortunately discovered that the material required for the encapsulation moulding would have to be a polyaddition curing resin, to give very high hardness and strength. The polyaddition resin would not bond to a polycondensation curing resin from which the spacer frame is made, however some success was noted when bonding polyaddition curing resin onto polycondensation curing resins. A Polycondensation cross-linking resin bonds to a cured polyaddition cross-linking resin but not vice versa.

Modifications were made to the plunger by drilling a centre hole in the shaft of the piston and inserting a sintered stainless steel disc at the base in order to vent the barrel. It was found that the resin was able to partly infiltrate the disc, so an air-permeable flat membrane plate was placed over the disc to prevent this. The plates were discarded after use.

2 Dow Corning Silastic T1

Properties :

Cure : Addition Colour : Translucent Mix : 10:1

Viscosity : 60000cp Hardness : 35 (Shore A) Cure time 18-24h

Results :

Dow Corning Silastic T1 resin offered a higher hardness than the first sample did but as it had double the viscosity, meant the mould could not be filled, and thus use of this resin was not justified. The sample which was received was beyond its expiry date and problems were experienced in obtaining a complete cure of the moulding. The problem of increasing the hardness by up to 40 or 50 (Shore A) without dramatically increasing the viscosity was now to be overcome. The low pressure equipment is unable to handle high viscosities as the large forces required to inject the material would damage the intricate mould. The solution to this came by incorporating up to 10% silicon oil in the mix (higher amounts resulted in a change in the physical properties of the cured moulding).The oil reduced the viscosity by approx. 30% which meant that a more manageable mix was obtained. For the addition of these other additives a variable speed rotary mixer was installed. Mixing by hand in a paper cup was no longer adequate (see fig 7).

The next problem that arose from the increased viscosity, even after using the oil, was that the venting of the mix became very difficult. Air bubbles trapped in the mix, during mixing, could not be removed by the small vacuum created by the venturi nozzle. The use of a vacuum oven which offered a vacuum of -950 mbar (see fig 6) worked well and the venturi nossle procedure, which may have been introducing moisture into our mould and thus inhibiting the curing process, was discarded. The mixed two-part silicon resin expands under vacuum to up to five times its original volume. Once all the entrapped air has surfaced, the mixture deflates and is ready for casting. This step is very important as it ensures void-free moulding.

FIG 6 : Removing air from a two-part silicon casting resin in a vacuum oven.

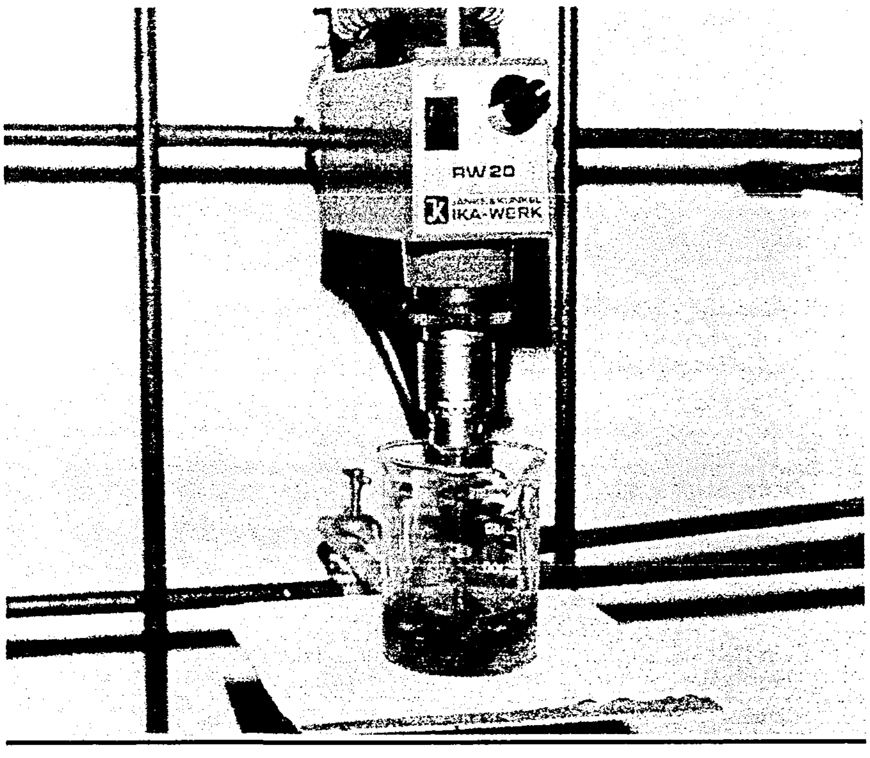


FIG 7 : Mixing of silicon resin with a variable speed mixer

3 General Electric YE 5626

Properties :

Cure : Addition	Colour : Transparent	Mix : 10:1
Viscosity : 55000cp	Hardness : 40 (Shore A)	Cure : 20h

Results :

The use of G.E. YE 5626 proved very successful. It had a lower viscosity than the Dow Corning sample (which could still be reduced using the oil) and a higher hardness. Experience has shown that the maximum hardness we could use without running the risk of breakage on removal was 45 (Shore A). We were now faced with the problem of trying to speed up the curing process without creating excessive exotherms or volatiles. We experimented with increased amounts of catalysts, but it was difficult to locate suppliers who were prepared to supply us with more catalyst than is supplied in the normal kit. They only have amounts corresponding to the specific mix ratio stipulated by the manufacturer. Although YE 5626 proved to be the most successful we had to stop using it as it was far too expensive (R650/kg).

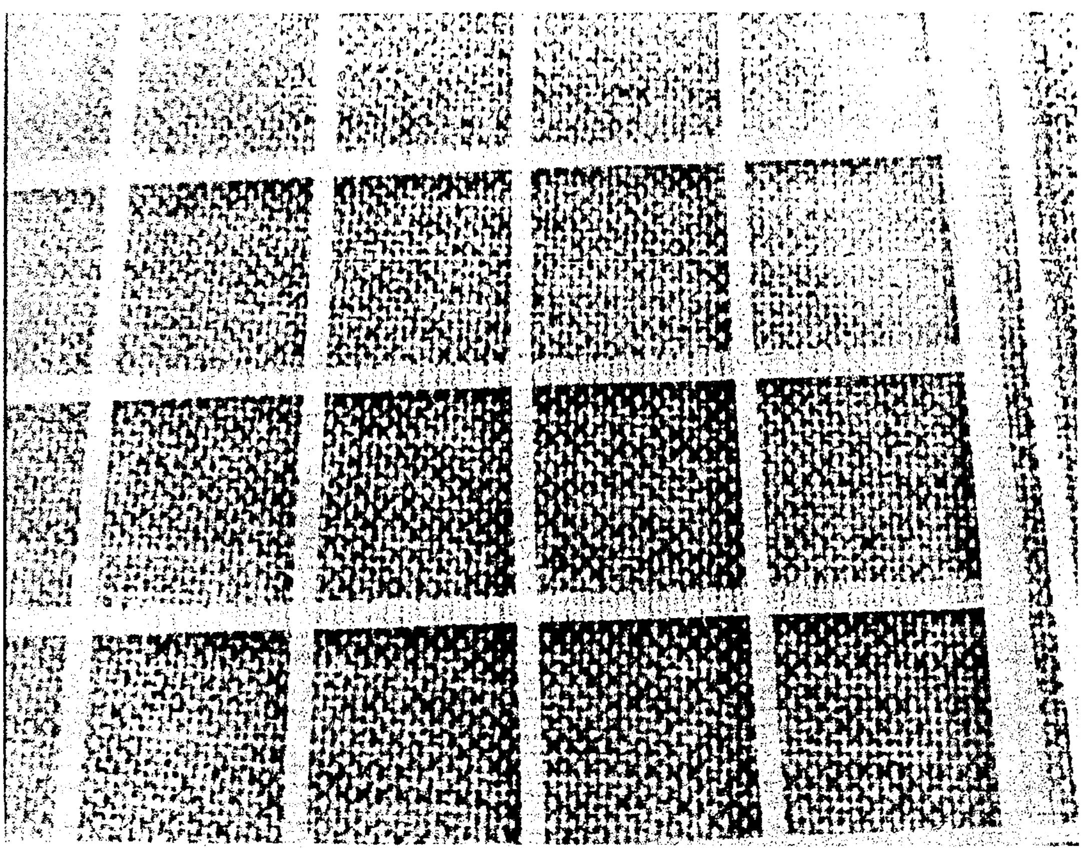


FIG 8 : Two spacers placed on top of each other in the assembly jig, showing the support lattice

4 Wacker Elastosil M4640

Properties:

Cure : Addition Colour : Transparent Mix :10:01

Viscosity : 50 000cp Hardness : 42 (Shore A) Cure : 24h

Results :

It was found that the Elastosil M4640 resin had very similar properties to the G.E. YE 5626 resin and was far more reasonably priced. It worked well, but had a rather long curing time which would have to be addressed. This was the resin that was finally chosen.

6 ENCAPSULATION MOULDS

The Four Clamping Bolt Mould

The first mould design incorporated a four clamping bolt square design which could be fully dismantled, to facilitate easy removal of the cured moulding. The open flow paths enabled the resin to flow unrestricted around the mould. The entire structure was assembled from HDPE sheet and screwed together using chip board screws. HDPE was chosen as it is tough and rigid, yet easy enough to machine. The property that disallowed bonding with silicon rubber was advantageous for the easy removal of the cured moulding. The bolting holes were created by the use of cylindrical inserts which fitted into the base of the mould and the flow channels by rectangular panels screwed onto the base of the mould. The spacer templates were positioned by four sunken pins, corresponding to the locating holes on the templates (see fig 9). The resin was poured into the mould with the mould at a slight inclination, to encourage the venting of air bubbles and complete encapsulation of the spacers. After a number of trials had been conducted it was noticed that the silicon templates required an additional loading force, over and above that of gravity, in order to keep the encapsulation resin from infiltrating between them. An overhead steel bar was bolted onto the top of the mould. This bar contained a centre bolt which, once the bar had been tightened onto the mould, provided the force on an additional HDPE block resting on the capillary filled spacers, to press down on the centre of the spacers and thus close up any leakage spots.
This arrangement worked well but it was found that it was very difficult to prevent the resin from entering the capillary ends during encapsulation. The second area of concern was that if the module was to operate under conditions of significant pressure it would tend to blow outwards, around the areas

between the clamping bolts, as this model gave little rigidity at those points. These problems led to the development of the eight clamp hole model.

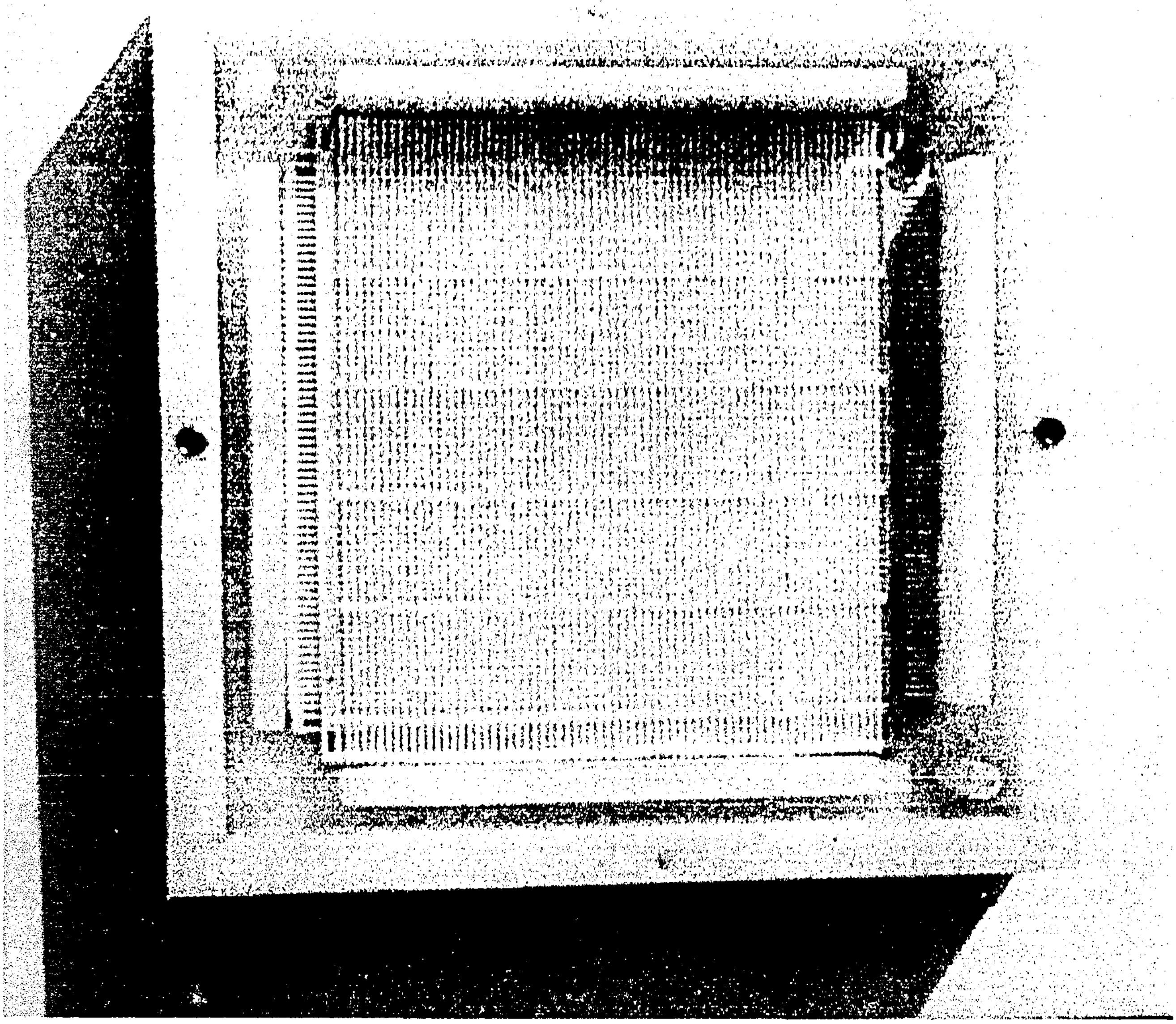


FIG 9 : Four-bolt module encapsulation mould with capillary-mounted spacers inserted , ready for encapsulation.

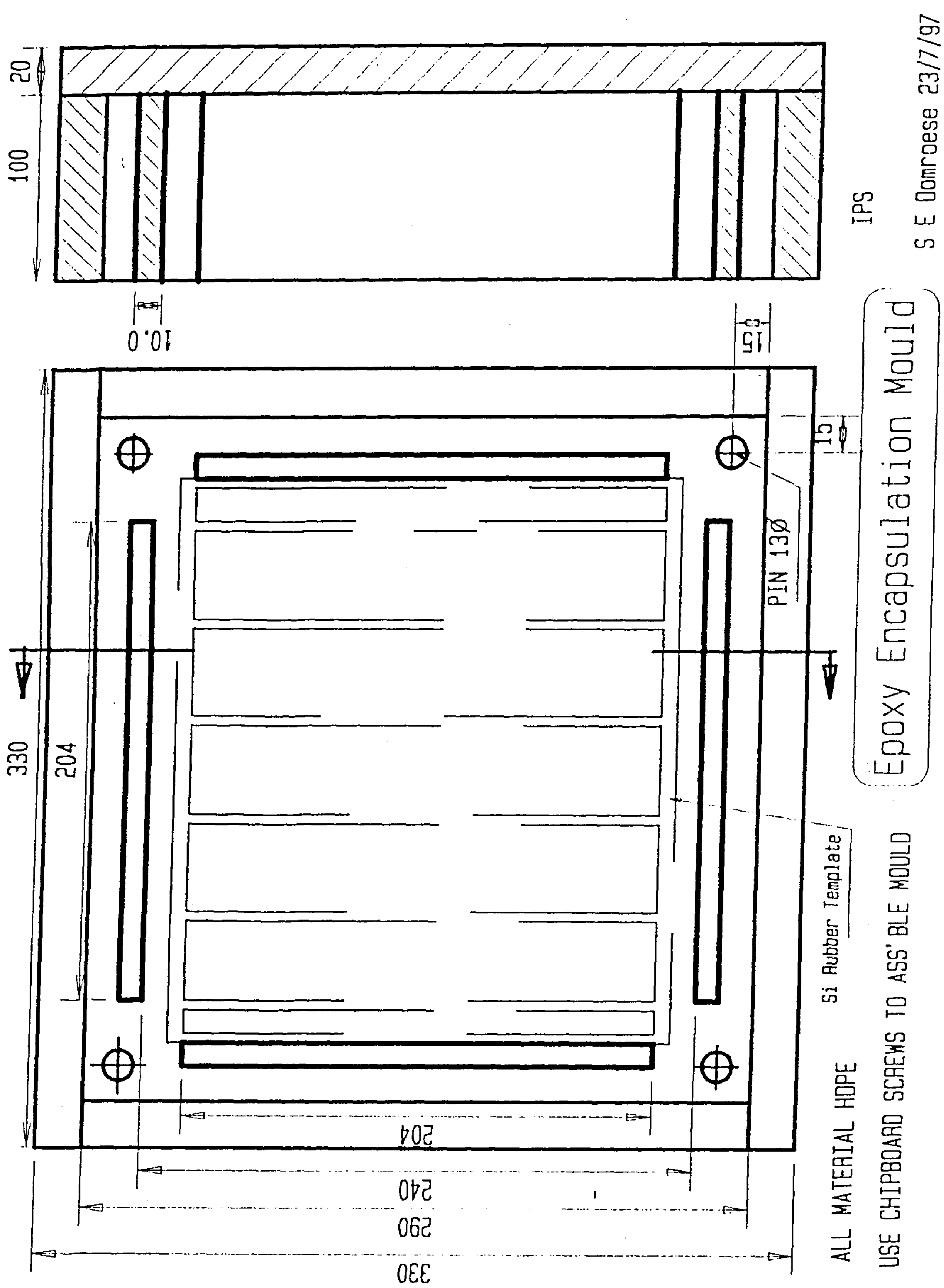


FIG : 10 DRAWING OF A FOUR-CLAMPING BOLT ENCAPSULATION MOULD

The Eight Clamping Bolt Mould

This mould was constructed using the same materials as the previous design and also made use of the overhead beam clamping system (see fig 11). The two main improvements were the addition of the four further bolt holes and the redesigning of the flow channel inserts.

The four additional bolt holes were included by adding four side bosses, in-between the existing bolt holes, into which the additional holes were sunk. This gave the entire unit a much improved rigidity and stability under pressure loads. This was further supplemented by the incorporation of polyester fibre in the resin to add to the stiffness.

The flow channel inserts were machined to give a 'U' profile which allowed the capillary ends to extend past the edge of the spacer by 6mm, thus leaving a lip which was later machined off after encapsulation (see fig 12). This alleviated the need to shut off the ends of the capillaries as they could now be simply squashed closed at the tip, or fused closed with a soldering iron or heated bar.

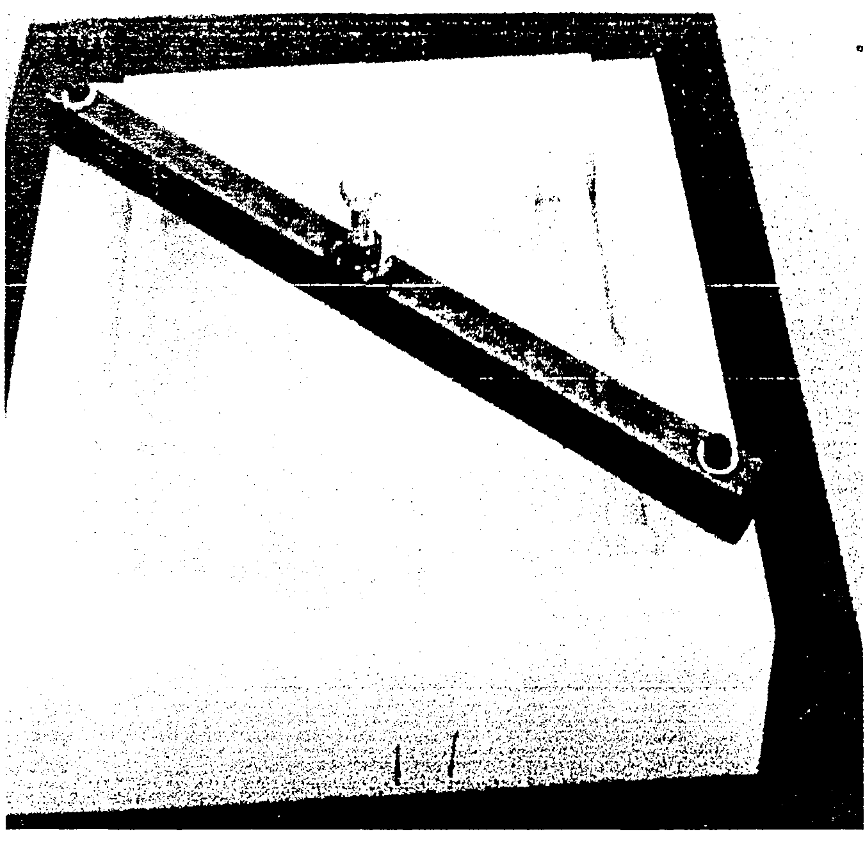


FIG 11 : Eight clamping bolt encapsulation mould with centre insert tightening screw and inserts for the clamping holes and secondary feed channels

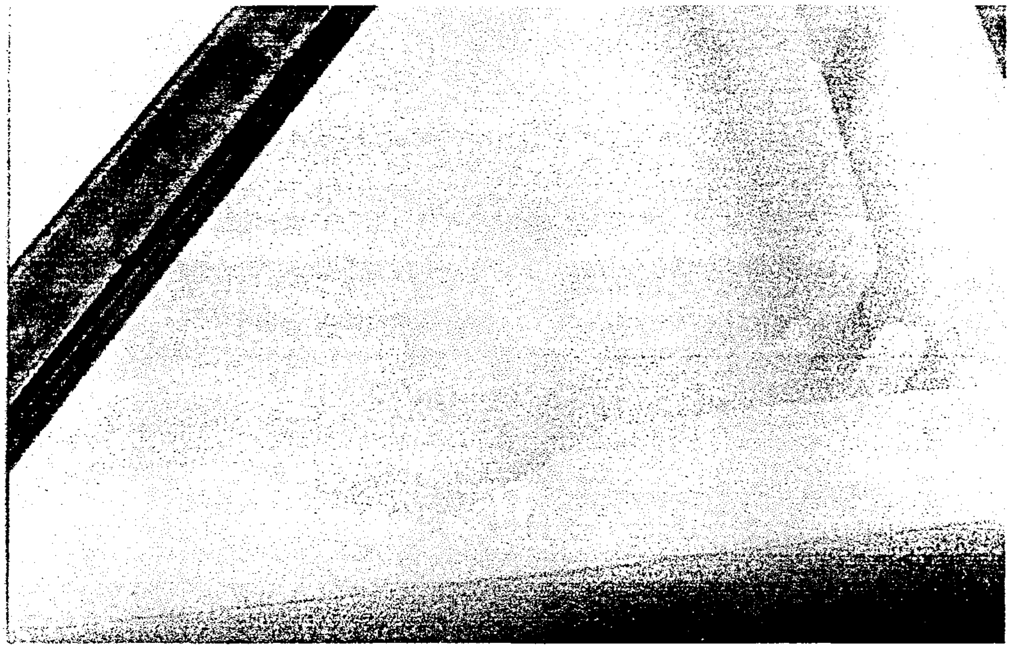


FIG 12 : Close-up of the eight clamping bolt encapsulation mould, showing the additional clamping holes and the modified flow channel inserts

7 SILICON RUBBER SELECTION AND EVALUATION OF ENCAPSULATION MATERIALS

Material Requirements

Encapsulation moulding requires a material with high hardness and rigidity which will be able to withstand the pressure applied during the purification process. It must be able to flow around and completely encapsulate the capillaries as any leaks would render the module useless. Three materials were evaluated for their effectiveness of encapsulation :

1 Dow Corning Silastic J

Properties :

Cure : Addition	Colour : Green	Mix : 10:1
Viscosity : 100000cp	Hardness : 55 (Shore A)	Cure time : 24h

Results :

In the first experiment with Dow Corning Silastic J, mixing was done manually. This lead to the mix not being homogeneous and curing was irregular. In the second experiment use was made of an electronic mixer (see fig 7) and the results were much better. The hardness of the first sample was too low and only slightly improved in the second attempt. This was due to the presence of glass spheres (5%). Unfortunately, neither of these mouldings was a true indication of the effectivity of the sample as no bonding took place between the spacer frame and the encapsulation resin (see fig 13).

We also experienced problems with working in the overnight laboratory where the distillation of NMP (N-Methylpyrollidone) was carried out, the NMP vapours inhibited the resin curing process. This shows that the working area must be free of solvent vapours and have good ventilation. The closing of the capillary ends during encapsulation had to be addressed, this could be done either by using a soft, low temperature, water soluble wax or by a water soluble glue. Both of these may well inhibit the curing process. A better route would be to truncate the capillary ends, encapsulate the flow channels and later cut them out using a 'Jig Saw'.

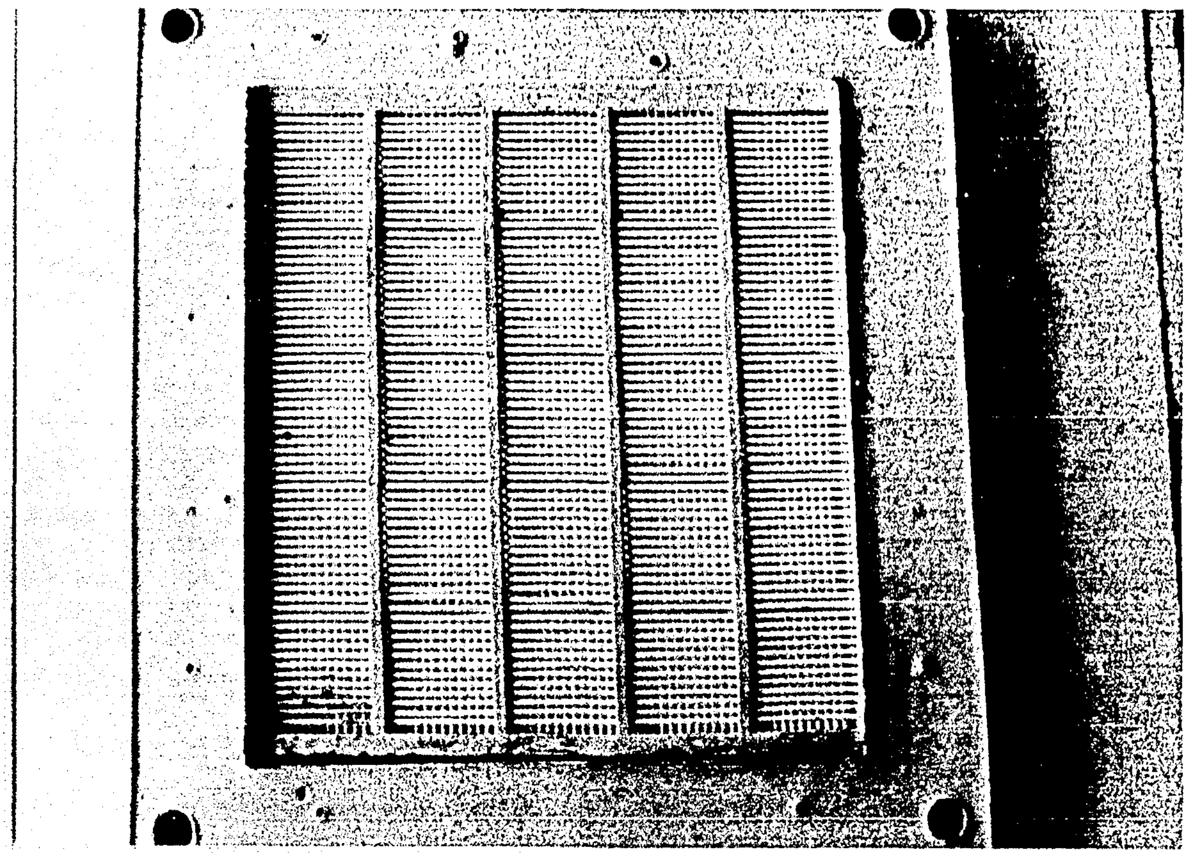


FIG 13: Encapsulated capillary membrane module with four clamping holes. (Note the uncured resin at the bottom of the model).

2 General Electric TSE 3466

Properties :

Cure : Addition Colour : Transparent Mix : 10:1

Viscosity : 63000cps Hardness : 60 (Shore A) Cure time 24h

Results :

Bonding tests showed that the GE TSE 3466 resin bonds successfully with the GE Ye 5626 resin and offers a good hardness, with an uncharacteristic low viscosity compared to that of the previous sample. The fact that the resin is transparent would simplify the 'jig saw procedure' as well as giving possible surveillance options during final end use. The first moulding we attempted was a three-template encapsulation and this turned out to be our first successful production (see fig 14). Both rigidity and complete encapsulation of the capillaries were achieved. Unfortunately, this resin was very expensive (R438/kg) and its use had to be disregarded.

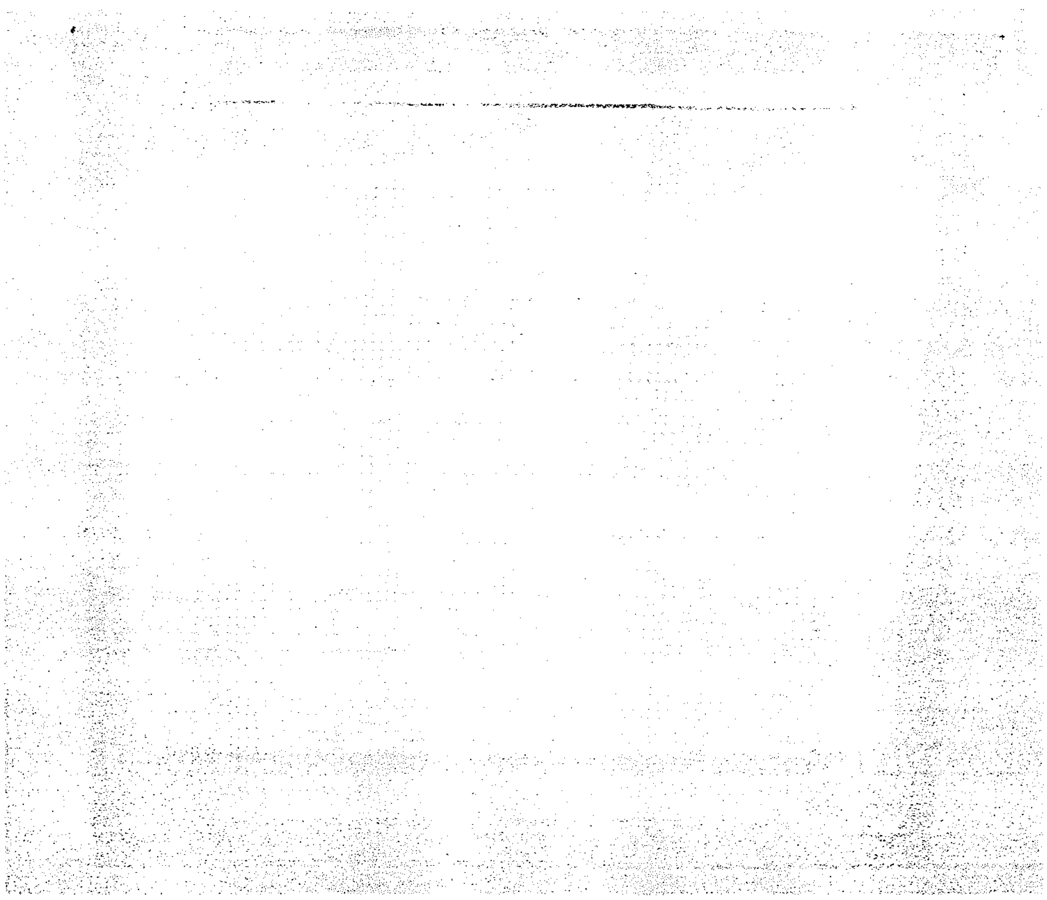


FIG.14: A successfully encapsulated transverse-flow capillary membrane module.

Before the next sample was tried, the mould was modified by adding in four side bosses which would house four additional pins to give the moulding further stability under the pressures foreseen to be required in the final use of the modules.

3 Wacker Elastosil M4370

Properties :

Cure : Addition Colour : Reddish Brown Mix : 10:01

Viscosity : 20000cp Hardness : 55 (Shore A) Cure : 12h

Results :

This resin had a very low viscosity which made it very easy to work with, i.e. venting was easy and complete encapsulation was easily achieved. The drawback of this resin was its very low tear strength. This made the use of fillers such as ceramic spheres and glass beads impossible as these materials added to the brittleness of the already brittle resin. Some success was achieved by using polyester fibres incorporated in the structure which increased the rigidity and tear strength. These tests were done by moulding test bars in which the fibre layout was easy to control. It was more difficult when moulding with the encapsulation mould. A method of aligning the fibres in the mould was developed by winding the fibres around the four cylindrical bolt inserts which were square to each other, thus creating a wall of fibre inside the model. This worked well and produced a rigid, tear-resistant structure (see fig 16).

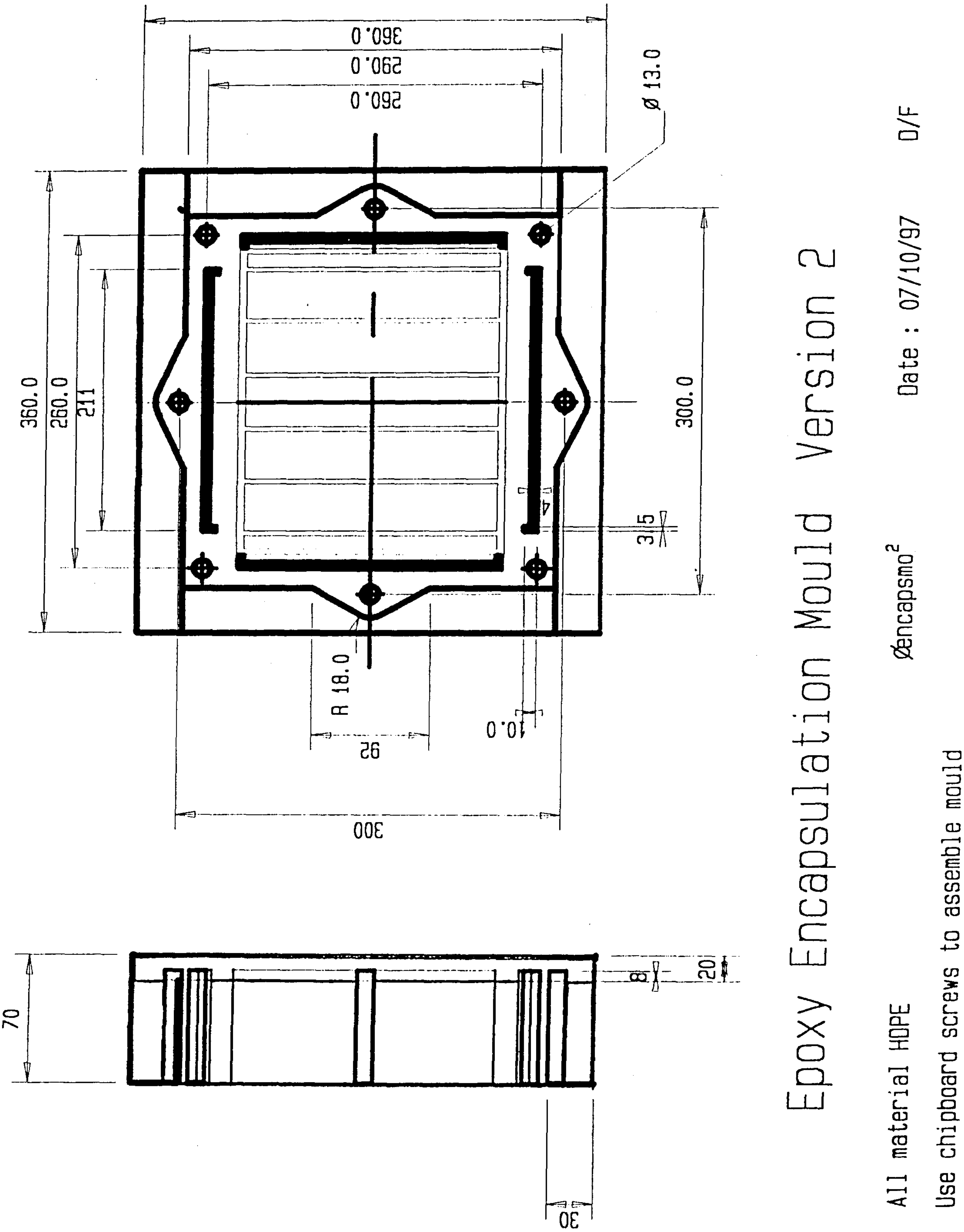


FIG.15 DRAWING OF 8-CLAMPING HOLE ENCAPSULATION MOULD

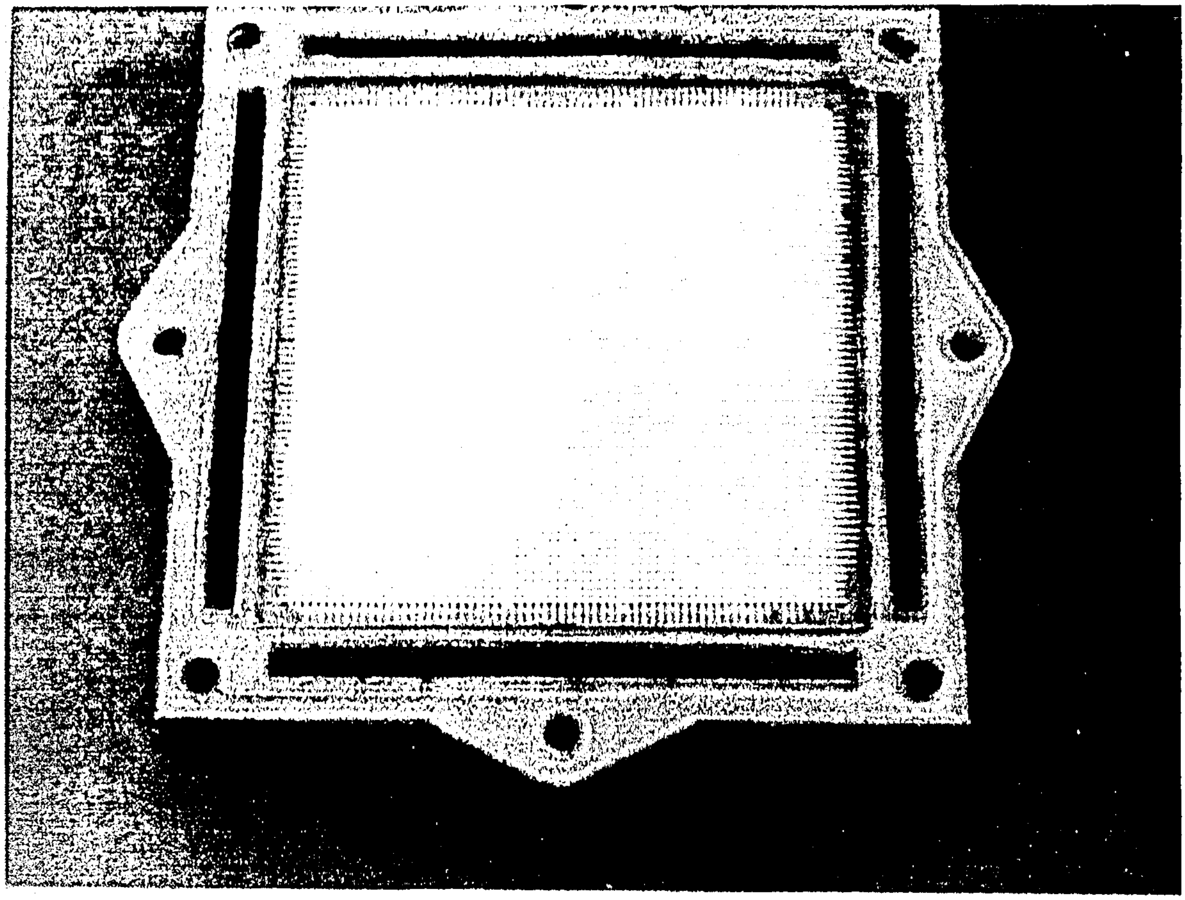


FIG 16 : A four-layer high, eight clamping bolts transverse flow module

8 ENCAPSULATION PRE ASSEMBLY

At present the capillaries are being inserted manually into the template. However, once the process reaches the stage of mass production, a new and more effective method will have to be developed. The hand method takes approximately 15 minutes per template. The use of some sort of jig and vacuum system to position the capillaries in the right place may be the answer. The spacer is placed in the PMMA assembly jig. As the capillaries are placed in the spacer they are cut in such a way as to create a 5mm overhang on either side of the spacer template. These protruding ends are then squashed closed (they remain closed as the material displays very little recovery). This is done in order to prevent any resin from entering the capillaries and clogging up the system. A heat sealing device could be used to make this process more efficient.

The encapsulation mould is assembled and cleaned with acetone to remove grime and moisture. The full spacer templates are then placed in the mould and located by the pins situated on the bottom of the mould, ensuring a perfect grid structure (see fig 17). The clamping plate is then placed over the effective membrane area and tightened. The device is now ready for encapsulation.

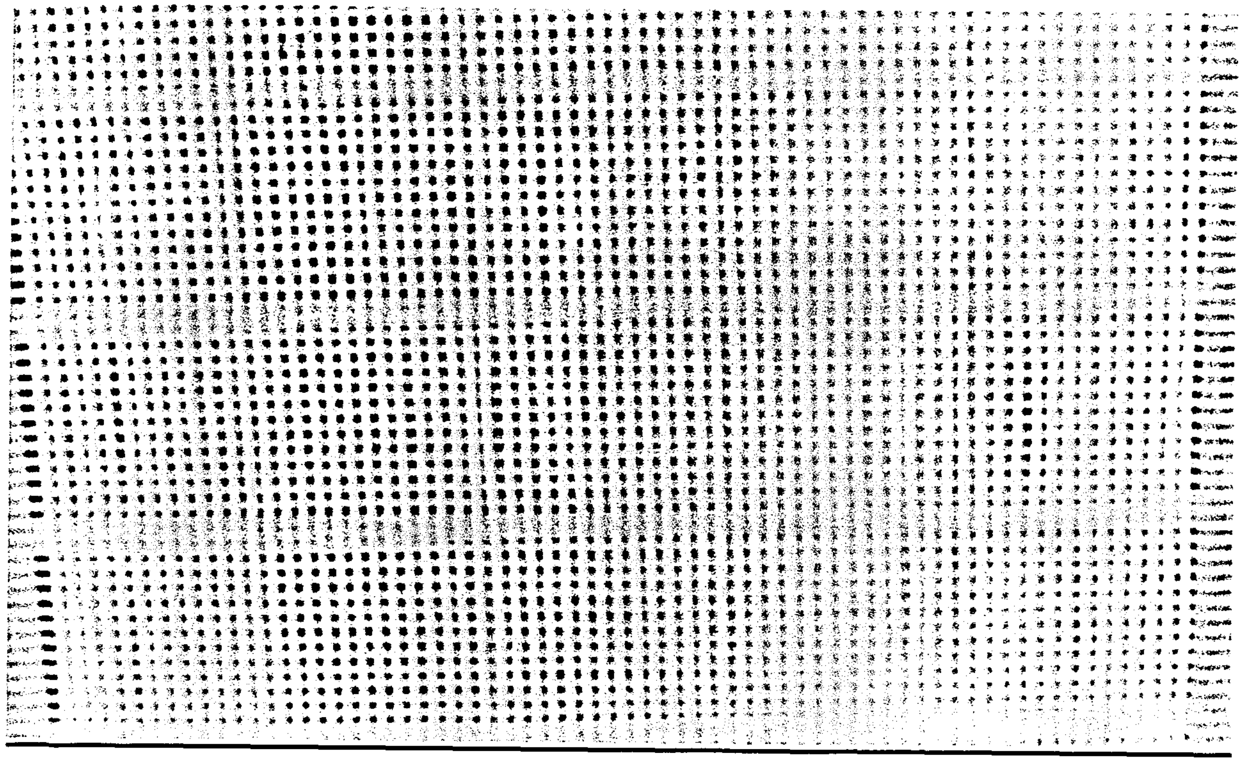


FIG 17 : Close-up view of the capillaries in a 90° offset pattern, located in the spacer frames of a module.

9 CUTTING OUT OF THE FOUR SECONDARY FLOW CHANNELS

Owing to the difficulty in shutting off the capillary ends before encapsulation, a new method had to be devised to produce the flow channels. The 'Jig Saw procedure' was one option but, owing to the large amount of wastage of silicon, it was not considered economical enough. A better solution was to take the existing mould inserts and thin them down on the inside edge by 3mm. This would still permit the use of the truncation procedure (nipping the capillary ends closed), but would provide three of the four walls of the flow channel being moulded during encapsulation, leaving only the last wall to be cut out and which would open up the capillaries (see fig 12). This would still involve a cutting method which had to be developed, but would save on silicon wastage. A cutting jig comprising a straight piece of wood along which a steel runner could glide, was developed. A Stanley blade was mounted onto the runner and when the whole device was placed in line with the required cut, the blade could be pulled through the silicon rubber and the encapsulated capillaries, producing a clean, straight cut and opening up the capillary ends (see fig 18).

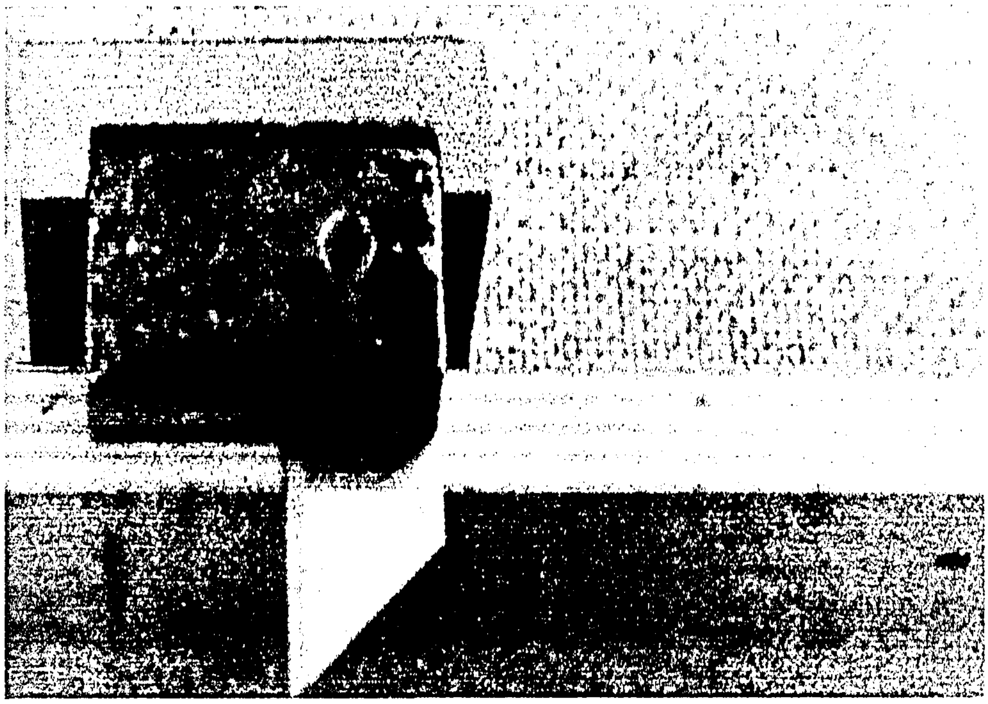


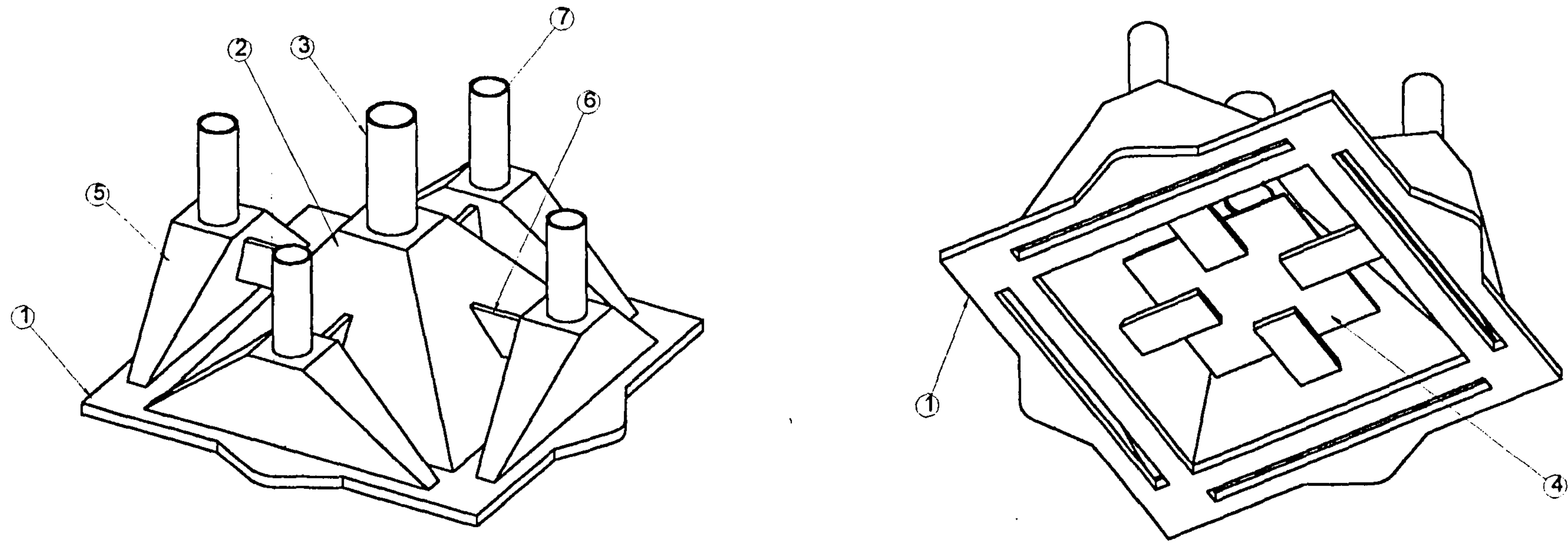
FIG 18 : Device used for cutting out the secondary flow channels

10 THE INLET AND OUTLET MANIFOLDS

The inlet and outlet manifolds were constructed from sheet SST and their design lends itself to cheap and easy manufacture. The inlet manifold (see fig 19) comprises a feed pipe which runs onto a distributing plate which keeps the flow from hitting the membranes at too fast a rate which could lead to damage within the capillary structure. A grid is situated below the distribution plate, providing support for the capillaries against the back pressures and high flow rates experienced during operation. The inlet manifold also contains the outlets for the flow channels which are supported by struts to the feed cone. The construction of the outlet manifold (see fig 20) is the same as that of the inlet manifold except that the outlet manifold contains no flow channels nor a distribution plate. It does contain a support grid and a concentrate outlet pipe.

FIG. 19 INLET MANIFOLD

USED ON	NEXT HIGHER ASSEMBLY
PSN-010010-103	-



ITEM NO.	QTY.	PART NAME	DESCRIPTION	SIZE	REFERENCE NO.
1	1	TOP BASE PLATE			PSN-010030-203
2	1	DOME			PSN-010031-203
3	1	TOP INLET PIPE	S/S PIPE	OD32x70 LNGx2,0 THK	-
4	1	TOP SPLASH PLATE			PSN-010032-202
5	4	TOP OUTLET			PSN-010033-203
6	4	TOP STRUT			PSN-010034-203
7	4	TOP OUTLET PIPE	S/S PIPE	OD25x70 LNGx2,0 THK	-

REV	DRAWN	DATE	PARTICULARS	ECP No

SCALE: 1:3 ON A3

AFRICA DESIGN SERVICES

DO NOT SCALE, USE DIMENSIONS. ALL DIMENSIONS ARE IN mm

MATL: SEE PARTS LIST

RESTRICTED

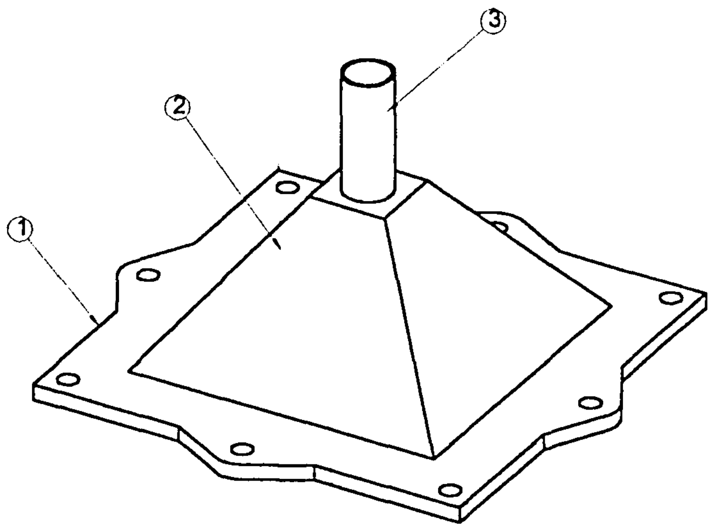
TITLE: TOP WELDED ASSEMBLY TRANSVERSE FLOW MODULE

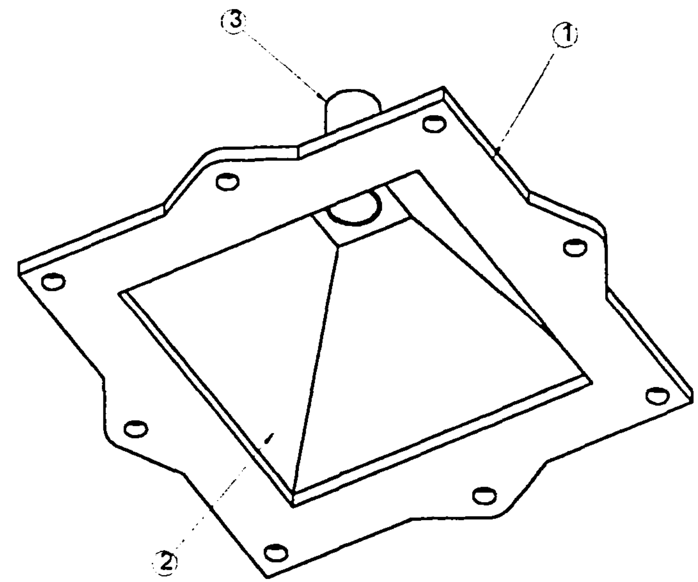
FINAL APPR		
APPROVED		
APPROVED		
CHECKED		
DRAWN	HS	17/11/97

CAD No:	DRG No:		Rev:
TOP WELDED ASS DRW DRW	PSN-010021-202	1 / 1	0

PSN-010010-103

FIG. 20 OUTLET MANIFOLD





ITEM NO.	QTY.	PART NAME	DESCRIPTION	SIZE	REFERENCE NO.
1	1	BOTTOM BASE PLATE			PSN-010050-203
2	1	DOME			PSN-010031-203
3	1	TOP INLET PIPE	S/S PIPE	OD32x70 LNGx2,0 THK	

REV	DRAWN	DATE	PARTICULARS	ECP No

SCALE 1:3 ON A3

AFRICA
DESIGN SERVICES

DO NOT SCALE. USE DIMENSIONS
ALL DIMENSIONS ARE IN mm

RESTRICTED

FINAL APPR		
APPROVED		
APPROVED		
CHECKED		
DRAWN	HS	17/11/97

MATL. SEE PARTS LIST

TITLE
BOTTOM
WELDED ASSEMBLY
TRANSVERSE FLOW MODULE

CAD No BOTTOM WELDED ASS DRW DRW

DRG No PSN-010022-202

1 / 1

Rev 0

11 FINAL MODULE ASSEMBLY

The final module assembly is designed to accommodate a varying number of transverse flow capillary modules, with the number depending on the end-use of the module. Typically a module would contain about 15 layers. The modules are bolted together using eight 12mm bolts, nuts and washers. Positioned on the ends of the stacked modules are the inlet and outlet manifolds (see fig 21).

The tie bolts are fastened with a torque wrench. Optimal torque must be achieved, ensuring complete sealing of the unit without over-stressing the silicon modules or damaging the capillary layout.

The entire system is to be fitted to a test rig containing inlet and outlet devices pressure gauges, flow meters and other analytical instruments.

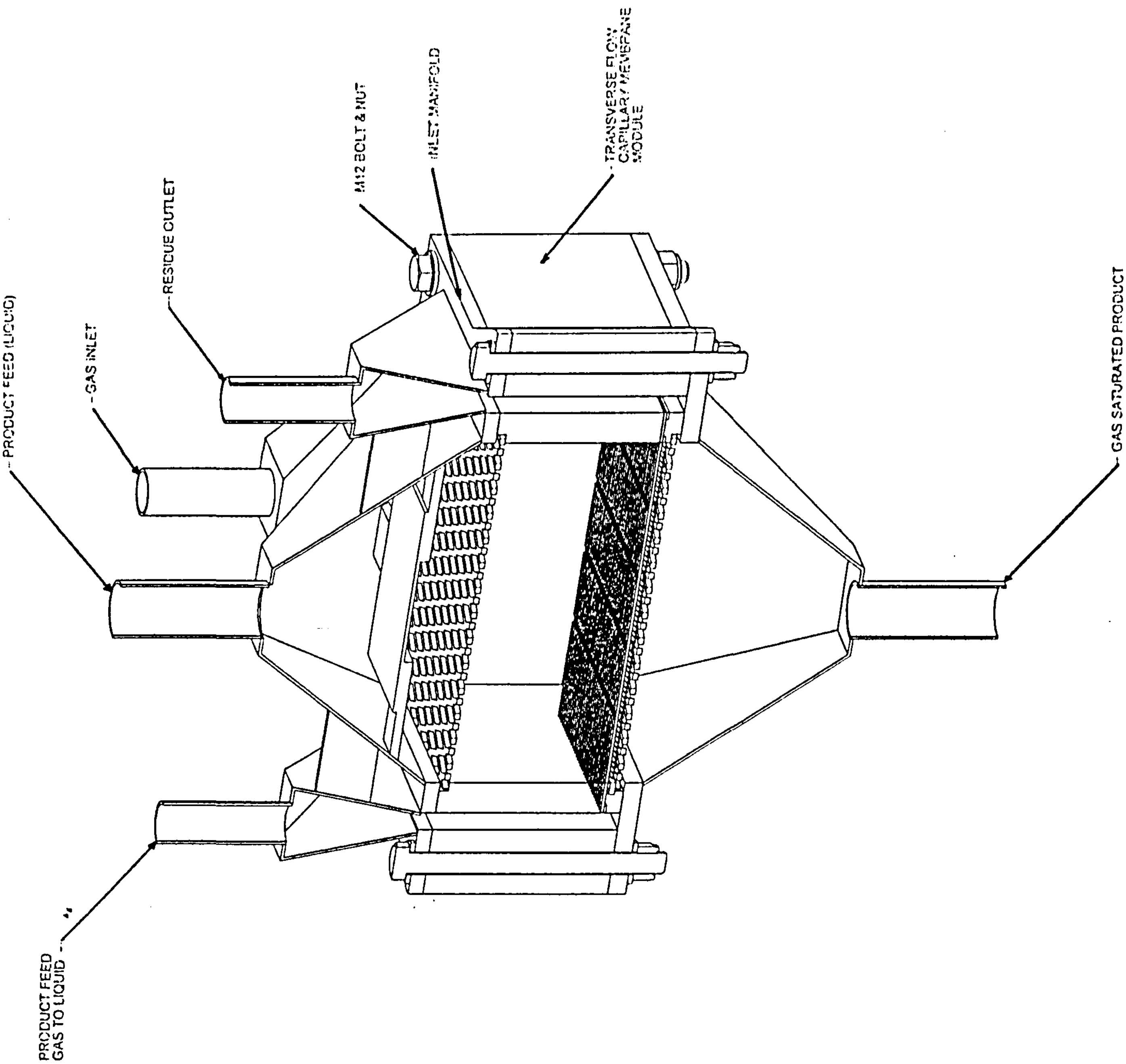


FIG. 21 GENERAL ASSEMBLY OF A TRANSVERSE FLOW CAPILLARY MEMBRANE MODULE.

12 COSTING FOR MANUFACTURING OF MODULES

Costing A : Two spacer castings a day. Module height 1m (333 spacers)

Labour	Unskilled	170 days @ R10/hour	R 13 600
	Supervised	40 hours @ R50/hour	R 2 000
	Skilled	30 hours @ R100/hour	R 3 000
		<u>Total Labour</u>	<u>R 18 600</u>
Materials	Capillaries, 67 × 0.26m @ R1/m		R 5 800
	Silicon spacer resin, 333 × 35g @ R160/kg		R 1 870
	Encapsulation resin, 1.6kg for 10 spacers		R 8 690
Attachments	Inlet manifold		R 3 000
	Outlet manifold		R 2 000
	SST bolts & nuts		R 200
		<u>Total Materials</u>	<u>R 21 560</u>
Tooling	Spacer mould		R 20 000
	Encapsulation mould		R 3 000
	Assembly template		R 500
	Design		R 5 000
		<u>Total Tooling</u>	<u>R 28 500</u>
Tooling amortized over 100 Modules, cost per module			<u>R 285</u>
Total cost per module for batch of 100 modules (approx.)			<u>R 40 445</u>

<u>Note</u> : Marketing and distribution to be added to this amount.

Costing B : 10 spacer castings a day. Module height 1m (333 spacers)

Note : Fast curing resin with an additional mould to be used

Labour	Unskilled, 333 spacers in 33.3 days @ 160/day		R	5 328
	Supervised, 40 hours @ R50 / hour		R	2 000
	Skilled, 30 hours @ R100 / hour		R	3 000
		Total Labour	R	10 328
	Materials	Capillaries	R	5 800
		Spacer resin	R	1 865
		Encapsulation resin	R	8 690
	Attachments	Inlet Manifold	R	3 000
		Outlet Manifold	R	2 000
		SST bolts & nuts	R	200
		Total Materials	R	21 555
	Tooling	Two spacer moulds	R	40 000
		Encapsulation mould	R	3 000
		Assembly template	R	500
		Design	R	5 000
		Total Tooling	R	48 500
	Tooling amortized over 100 modules, cost per module		R	485
	Total cost per module for a batch of 100 modules (approx.)		R	32368

Note : Marketing and distribution to be added to this amount.

13 COMPARISON OF THE LABORATORY TRANSVERSE FLOW CAPILLARY MODEL WITH THE INDUSTRIAL ONE

The laboratory transverse flow model made use of 10 equally-spaced capillaries of length 30.1mm. These capillaries had a bore of 1.35mm. In order to calculate the capillary surface area for one template the following formula is used :

$$\text{Surface Area} = \text{Bore (m)} \times \pi \times \text{Length (m)} \times \text{No of capillaries}$$

$$\text{Laboratory model surface area (SA)} = 0.00135 \times \pi \times 0.031 \times 10$$

$$= \underline{0.001314756\ m^2}$$

The Industrial Transverse Flow model makes use of 67 equally-spaced capillaries of length 188mm. These capillaries have the same bore as those used in the lab model. Thus, by using the above formula the surface area of the industrial module can be calculated.

$$\text{Industrial Model surface area} = 0.00135 \times \pi \times 0.188 \times 67$$

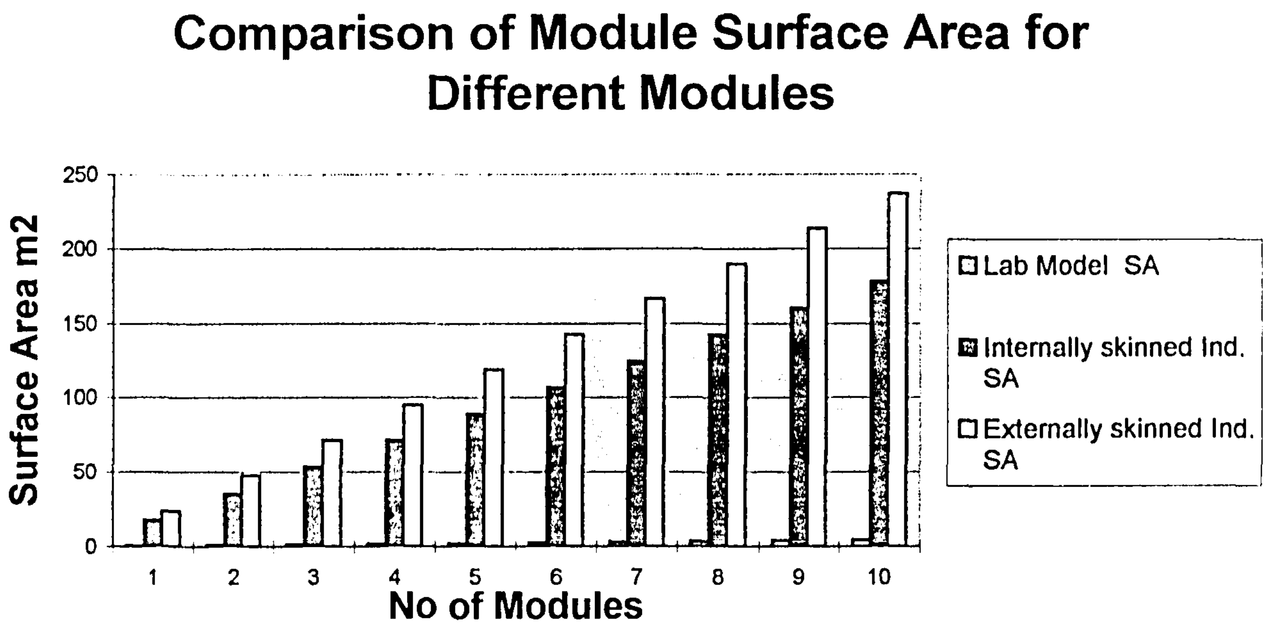
$$= \underline{0.053421526\ m^2}$$

From the above results it can be seen that the industrial template has a surface area 40.6 times larger than that of the laboratory template.

If externally skinned capillaries were to be used instead of internally skinned capillaries, the bore would change to 1.80mm, thus giving a surface area of $\underline{0.071228828\ m^2}$.

Comparatively, if modules of length 1m were to be made, 333 templates would be needed in both the lab and the industrial models (both templates have a height of 3mm). This would give the following surface areas:

Laboratory Template :	0.4378 m^2	
Industrial Template :	17.7886 m^2	(internally skinned)
Industrial Template :	23.7191 m^2	(externally skinned)



GRAPH 1

14 MODULE PREFORMANCE

The module performance, in terms of flux, is based on tests done with skinless capillary membranes of 1.8mm OD and 1.35 ID at 20°C, having a flux of 600 lmh/100kPa. Results are presented in table 1

TABLE 1 : Module performance

No of layers	Membrane area m^2	Flux (lmh) ΔP at 40 kpa at 30°C, Velocity 0.42m/s	Flux (lmh) ΔP at 100 kpa at 20°C, Velocity 1m/s
1	0.0539	2.10	32.4
10	0.5390	21.02	324
100	5.390	210.21	3240
200	10.780	420.42	6480
300	16.170	630.63	9720
333	17.950	700.05	10789

HYDROSTATIC TESTING

The model was hydrostatically tested to check all the seals and ensure that no feed was able to infiltrate the permeate which would render the device useless. A 25 l tank was placed six meters above the sample, giving a pressure of 60kpa. Once the tap on the tank was opened the water flowed down a pipe and entered the model through the two inlet feed pipes. The two residue outlets were blocked off, thus making the test a static one. The permeate was collected from the permeate outlet pipe. A congo red dye was placed in the tank and this was then introduced into the model. The permeate remained clear, indicating that there was no leakage between the feed and permeate channels. This proved that our encapsulation procedure worked and that the capillaries had not been damaged during their insertion into the spacer and the clamping of the manifold. Under these conditions of dead end flow, a flux of 468 l/hour was obtainable. However, when the model is tested under circulating flow this figure will be much higher.

15 POSSIBLE FUTURE USES AND APPLICATIONS

1. Waste water treatment : Ozonation, water denitrification, de-oxygenation (power plants)
2. Industrial effluent treatment, dye house paint plating, leather tanneries, paint industry.
3. Oxidation of drainage streams
4. Bioreactors for cell cultures
5. Water filtration (removal of bacteria and cloudiness)
6. Water aeration
7. Petro chemical applications : gas separation, emulsion breaking, catalytic bioreactor for the hydrolysis of mixed natural oils
8. Pharmaceutical applications : production of beta keratin, antibiotics, penicillin, tetracyclines, steroids, amino acids, insulin, human growth hormones, vitamins
9. Nanofiltration for the desalination of sea water
10. Aerobic waste water treatment
11. Pressurised bioreactors

12. Biological water treatment

13. Bio-technology applications : bioconversion, enzyme inhibition, enzyme kinetic studies, enzyme immobilization, down-stream bio- tech processing (protein concentration)

14. Hydrometallurgy, bio-leaching

15. Production of biological detergents

16. Production of manganese peroxidase

17. Food technology applications : CO_2 production, beverage industry, dairy industry, bakers yeast, fermentation, wine filtration

18. Purification of air-conditioned air, removal of bacteria and fungus spores.

19. Carbon dioxide separation.

16 OPTIONS FOR VARIABLE CAPILLARY AND FIBRE USE

Due to the versatility of the mould designs and encapsulation procedure many variations of the model can be achieved. The pitch and capillary layout can be manipulated in such away as to facilitate most types of capillary, tubular or even hollow-fine fibre membranes. By simple mould insert changes the dimension, locating and nesting features can easily be modified to suit a particular application. Below is a table giving some of the possible membranes which could be used in this model.

TABLE 2.0 Membranes possibly suitable for use in the transverse-flow capillary-membrane module

COMPANY	COUNTRY	CAPILLARY	TYPE	MATERIAL
Institute for Polymer Science	**RSA**	**1.8mm OD 1.35mm ID**	**Skinless UF**	**Polysulfone**
Memtec	**Australia**	**0.7mm OD ? ID**		
Microdyn	**Germany**	**9mm OD 5mm ID**	**Support netting**	**HDPE**
"	"	**2.5mm OD 1.61mm ID**		**HDPE**
"	"	**1mm OD 0.4mm ID**		**HDPE**
"	"	**0.2mm OD ? ID**	**Hollow fine fibre**	
Nitto Denko	**Japan**	**1.0mm OD 0.55mm ID**	**UF**	**Poly sulfone**
Nedo	**Japan**	**2mm OD 1.4mm ID**	**UF**	**Ceramic**

17 CONCLUSIONS

Research results and products have exceeded the objectives of this project. The membrane area has increased 40 fold over the laboratory-type transverse flow module. Exciting new possibilities can now be explored with the industrial size module in follow-up projects. The manufacturing system developed is such that it can be applied to much larger locating spacer-frames, housing 200 or more capillary membranes per layer. Overleaf are the membrane areas, in m^2, for modules with 333 layers forming a 1m high unit. Externally-skinned capillary membranes result in about 25% higher module membrane areas than internally-skinned membranes.

Laboratory module :

10 capillaries/layer x 333 layers high = 0.43 m^2 (internally skinned)

= 0.58 m^2 (externally skinned)

Industrial module :

67 capillaries/layer x 333 layers high = 17 m^2 (internally skinned)

= 24 m^2 (externally skinned)

Future module :

200 capillary/layer x 333 layers high = 186 m^2 (internally skinned)

= 250 m^2 (externally skinned)

18 RECOMMENDATIONS

At the discretion of the of the WRC, pilot or field studies should be initiated to fully explore some of the possible applications of the new module. These could be for water purification, recycling, treatment of effluent and provision of water for industrial applications, for food processing, breweries, carbonation of mineral water, pharmaceutical and electronic processes and bio-leaching. Herefore, more modules and pilot plants will be required.

TABLE A1 : Spacer frame casting record

Sheet1

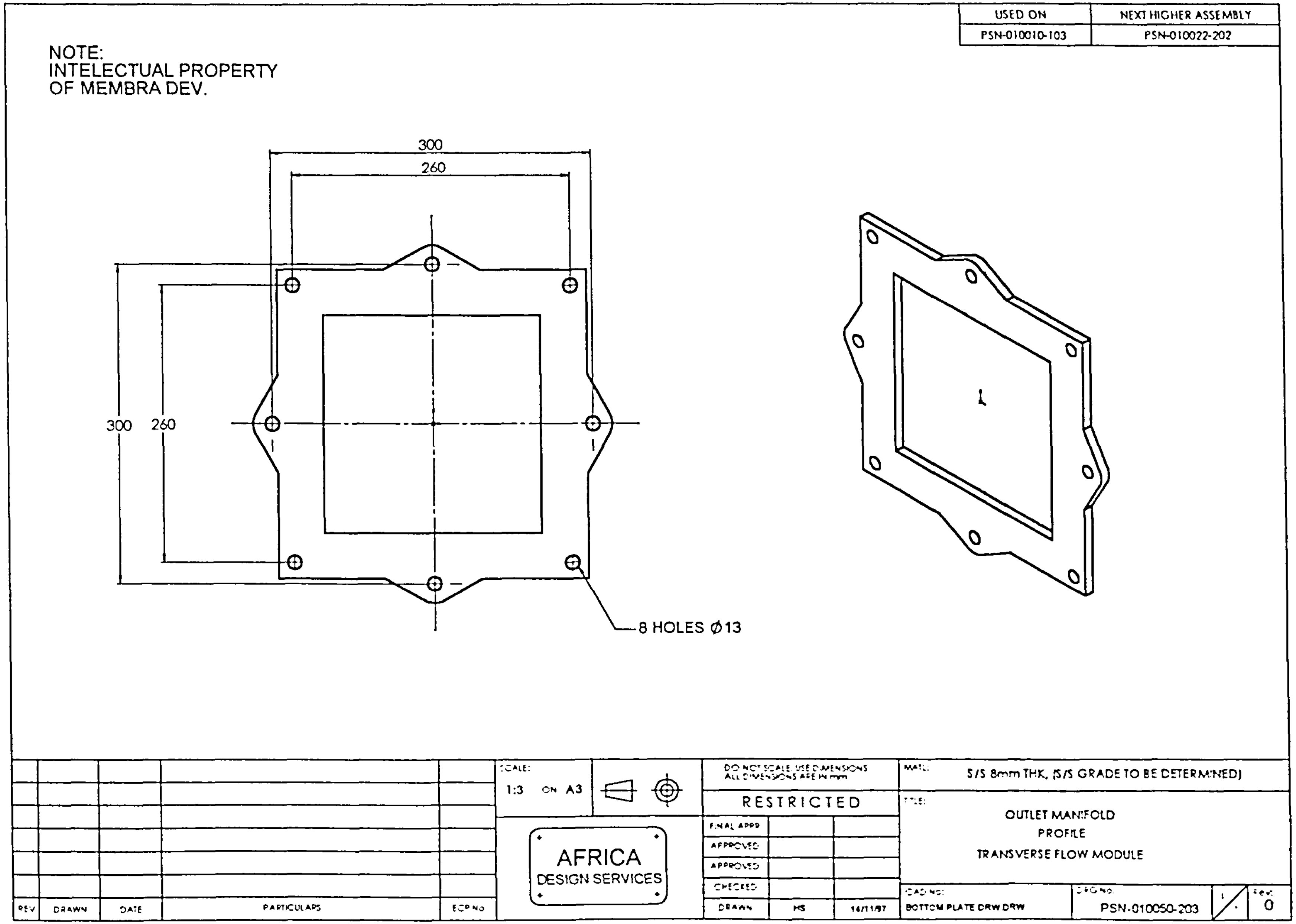
Moulding	Date	R/C Ratio	Resin (g)	Catalyst (g)	Pressure	Vacuum	Clamping Nm	Mass
1	15/08/97	15:01	45	3.20	Experimental	No	N/A	28 96
2	18/08/97	15:01	40	2.73	No	Yes	N/A	26 24
3	19/08/97	12.5:1	40	3.20	After vac fill	Initial till fill	In 60,Out 30	27.26
4	20/08/97	10:01	40	4.00	Throughout	Initial till fill	In 60,Out 30	27.15
5	21/08/97	10:01	40	4.12	Throughout	Initial till fill	In 60,Out 30	27 44
6	21/08/97	10:01	40	4.07	Throughout	Initial till fill	In 60,Out 30	27 59
7	22/08/97	10:01	40	4.10	Throughout	Initial till fill	In 60,Out 30	28 28
8	22/08/97	10.01	40	4.00	Throughout	Initial till fill	In 60,Out 30	25 80
9	25/08/97	10.01	40	4.10	Throughout	Initial till fill	In 60,Out 30	22 98
10	25/08/97	12.5:1	40	3.20	Throughout	Initial till fill	In 60,Out 30	29 69
11	26/08/97	11.56:1	35	3.16	Throughout	Initial till fill	In 60,Out 30	32.16
12	26/08/97	11.6:1	35	3.20	Throughout	Initial till fill	In 60,Out 30	33 23
13	27/08/97	10 01	35	3.50	Throughout	Initial till fill	In 60,Out 30	N/A
14	03/09/97	10.01	30	3 00	Throughout	Initial till fill	In 60,Out 30	N/A
15	04/09/97	10.01	30	3 00	Throughout	Initial till fill	In 60,Out 30	N/A
16	05/09/97	10 01	35	3 50	Throughout	Initial till fill	In 60,Out 30	23 83
17	08/09/97	5 01	35	7.00	Throughout	Initial till fill	In 60,Out 30	N/A
18	09/09/97	15 01	35	2.30	Throughout	Initial till fill	In 60,Out 30	N/A
19	10/09/97	15 01	35	2 30	Throughout	Initial	In 60,Out 30	N/A
20	11/09/97	15 01	35	2 30	Throughout	Initial till fill	In 60,Out 30	N/A
21	14/09/97	15 01	35	2 30	Throughout	Initial till fill	In 60,Out 30	25 92
22	15/09/97	17.01	35	2 00	Throughout	Initial till fill	In 60,Out 30	26 98
23	16/09/97	17 01	35	2 00	Throughout	Initial till fill	In 60,Out 30	26 42
24	17/09/97	15 01	35	2 30	Throughout	Initial till fill	In 60,Out 30	N/A
25	18/09\97	10 01	50	5 00	Throughout	Initial till fill	In 60,Out 30	23 16
26	19/09/97	10 01	35	3 50	Throughout	Initial till fill	In 60,Out 30	N/A
27	22/09/97	10 01	35	3 50	Throughout	Initial till fill	In 60,Out 30	N/A
28	25/09/97	10 01	35	3 50	Throughout	Oven	In 60,Out 30	22 20
29	26/09/97	10 01	35	3 50	Throughout	Oven	In 60,Out 30	22 19
30	29/09/97	10 01	35	3 50	Throughout	Oven	In 60,Out 30	22 10
31	30/09/97	10 01	35	3 50	Throughout	Oven	In 60,Out 30	22 10
32	01/10/97	10 01	35	3 50	Throughout	Oven	In 60,Out 30	22 13
33	02/10/97	10 01	35	3 50	Throughout	Oven	In 60,Out 30	22 05
34	06/10/97	10 01	25	2.50	Throughout	Oven	In 60,Out 30	N/A
35	08/10/97	10 01	35	3 50	Throughout	Oven	In 60,Out 30	19 48
36	9/10/97	10 01	35	3.50	Throughout	Oven	In 60,Out 30	20 98
37	17/10/97	10 01	32	3 20	Throughout	Oven	In 60,Out 30	22.38
38	27/10/97	10 01	32	3.20	Throughout	Oven	In 60,Out 30	20 79
39	27/10/97	10:01	33	3 30	Throughout	Oven	In 60,Out 30	21 04
40	28/10/97	10 01	33	3 30	Throughout	Oven	In 60,Out 30	21.10
41	29\10/97	10 01	33	3.30	Throughout	Oven	In 60,Out 30	20 88
42	3/11/97	10 01	33	3 30	Throughout	Oven	In 60,Out 30	21 09
43	4/11/97	10 01	33	3.30	Throughout	Oven	In 60,Out 30	20 86
44	4/11/97	10 01	33	3.30	Throughout	Oven	In 60,Out 30	20 72
45	5/11/97	10 01	33	3.30	Throughout	Oven	In 60,Out 30	21 12
46	6/11/97	10 01	33	3 30	Throughout	Oven	In 60,Out 30	20 84
47	10/11/97	10 01	33	3 30	Throughout	Oven	In 60,Out 30	20 93
48	11/11/97	10 01	33	3 30	Throughout	Oven	In 60,Out 30	20 98
49	12/11/97	10 01	33	3.30	Throughout	Oven	In 60,Out 30	20 14
50	13/11/97	10 01	33	3.30	Throughout	Oven	In 60,Out 30	21 23

Silicon Moulding Log

TABLE A1 cont. : Spacer frame casting record

Comments
1) General Electric RTV 428. Experimental venting of plunger with wire,suck back occured.#Too much mix,reduce to 40g.
2) No elevation of mould,resulting in too many voids.Slow filling +/- 25 min,bubbles for +/- 25min.
3) Less voids,plunger not completely depressed.Inconsistent force on plunger.Bubbles for +/- 10min
4) Consitant force on plunger (vice).Double elevation,complete depression.Less bubbles after filling (2-3min)# Too many voids appearing on teeth.
5) As above. +three elevations. #Still to many voids on teeth
6) As above. #Too many voids on teeth
7) As above + four elevations,#Less voids
8) 1.0g Glass beads added, viscosity increased dramatically(vice+toolbox+chair).#Improved hardness and DS
9) 2.0g Glass beads added, viscosity too high,very diffucult moulding.#Zero voids. Same hardness and DS as above
10) 6.0g talc added.viscosity still low. Less presure required (vice).#Large internal voids,because air trapped in plunger.Increase talc to 10g
11) 10g talc used,viscosity optimum. Vice and toolbox used. Mix allowed to settle before application of vacuum and pressure to allow bubbles to escape. Mix could be lowered to 30g.Homogenious ? alternative mixing method ?
12) As above + large pressure and back pressure, allow longer curing
13) As above with new catalyst(Waker), drop in viscosity,8g of talc.#**NO RESULT, CATALYST DID NOT WORK.**
14) Sample used to clean out mould.#Unable to remove all uncured resin.**DUMPED**
15) Sample used to clean out mould.#**DUMPED**
16) New resin (Silastic T1) Highly viscous,small bubbles - desecate while mixing next time.**DUMPED**
17) Solution must be vented.#Voids again, Break on removal. **DUMPED**
18) Voids, break on removal, water contamination, **Back to rtv 428 .DUMPED**
19) 15g Talc added, very high viscosity.Car jack used. Too brittle,breaks on removal, reduce talc loading to 12g **DUMPED**
20) 12g Talc added ,better viscosity.Body weight used for pressure.No complete fill **Dumped**
22) 2 g Talc. Viods on teeth. Venting piston clogged up Toluene tried as solvent, only disolves uncured mix. Benzene has no effect
23) 4g Talc added. Moulding removed to early(6hours). Otherwise OK Warpage after 48HRS
24) 6.5g Talc added. Mixed with drill bit .Break on removal
25) New resin GE YE5626 ,small bubbles.# Good moulding, try silicon oil next 10%
26) Add 3.5g of silicon oil, viscosity dropped dramatically. bubbles still a problem.Break on removal because of bubbles
27) Add 1.5g of silicon oil, still low viscosity .Breakage on removal huge voids.
28) Mould modified (inlet hole increased. plunger vented using membrane plate.)Vacuum oven used to vent out air 2000 mbar 15min
29) As above #Good moulding
30) As above# Good moulding
31) As above# Good moulding. break on removal opposite runner, must be cut before removal. Patched up and trimmed.
32) As above
33) As above
34) Short shot, end of resin pot. DUMPED
35) Silastic t1 10% oil 20% Ceramic spheres Viscosity still low # Tiny voids everywhere only partialy cured after 24Hrs ,heat treated
36) As above without the oil and 10% ceramic spheres
37) New resin Wacker Elastosil M4640. Easy mouldability, easy to vent. #Good moulding
38) Attempted oven cure to speed up curing. # Voids
39) As above no Oven cure. Sample takes 24 Hrs to set
40) Good MOULDING
41) Good MOULDING
42) Good MOULDING
43) Good MOULDING
44) Good MOULDING Break on removal
45) Good MOULDING
46) Good MOULDING
47) Good Moulding
48) Good Moulding
49) Good Moulding
50) Good Moulding
Silicon Moulding Log

FIG A1 : Eng. detail dwg. outlet manifold profile



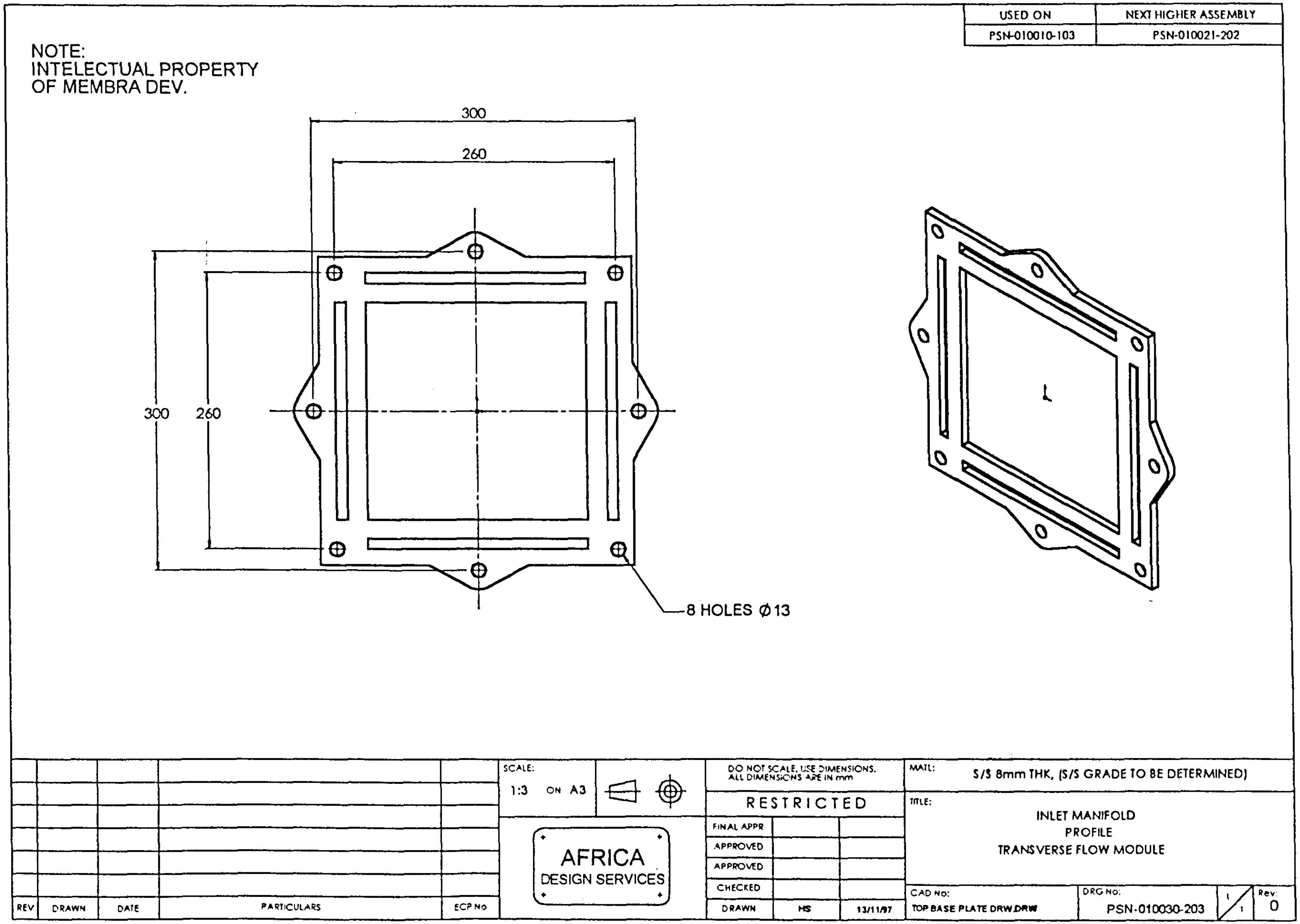


FIG A2 : Eng. detail dwg. inlet manifold profile

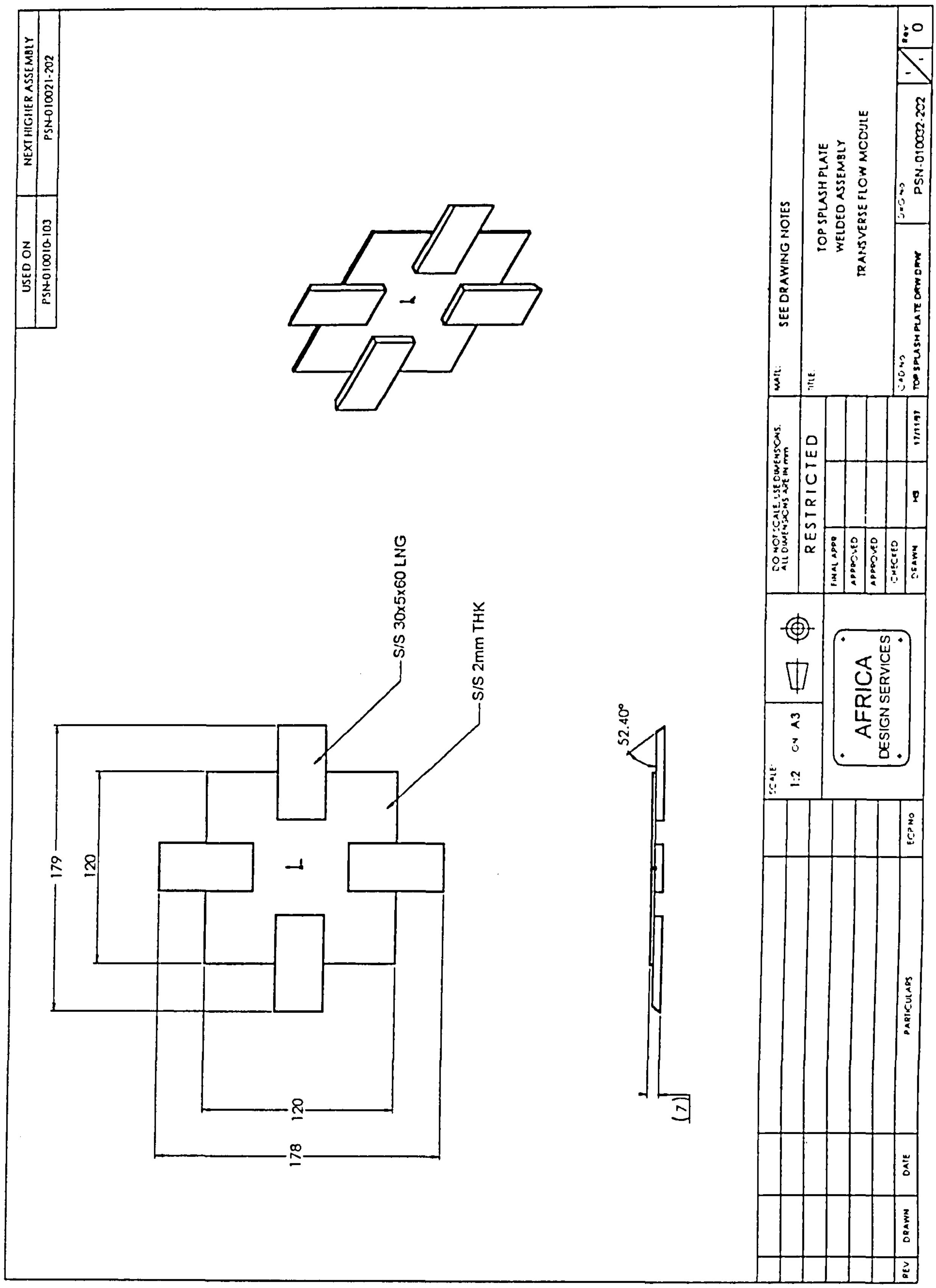
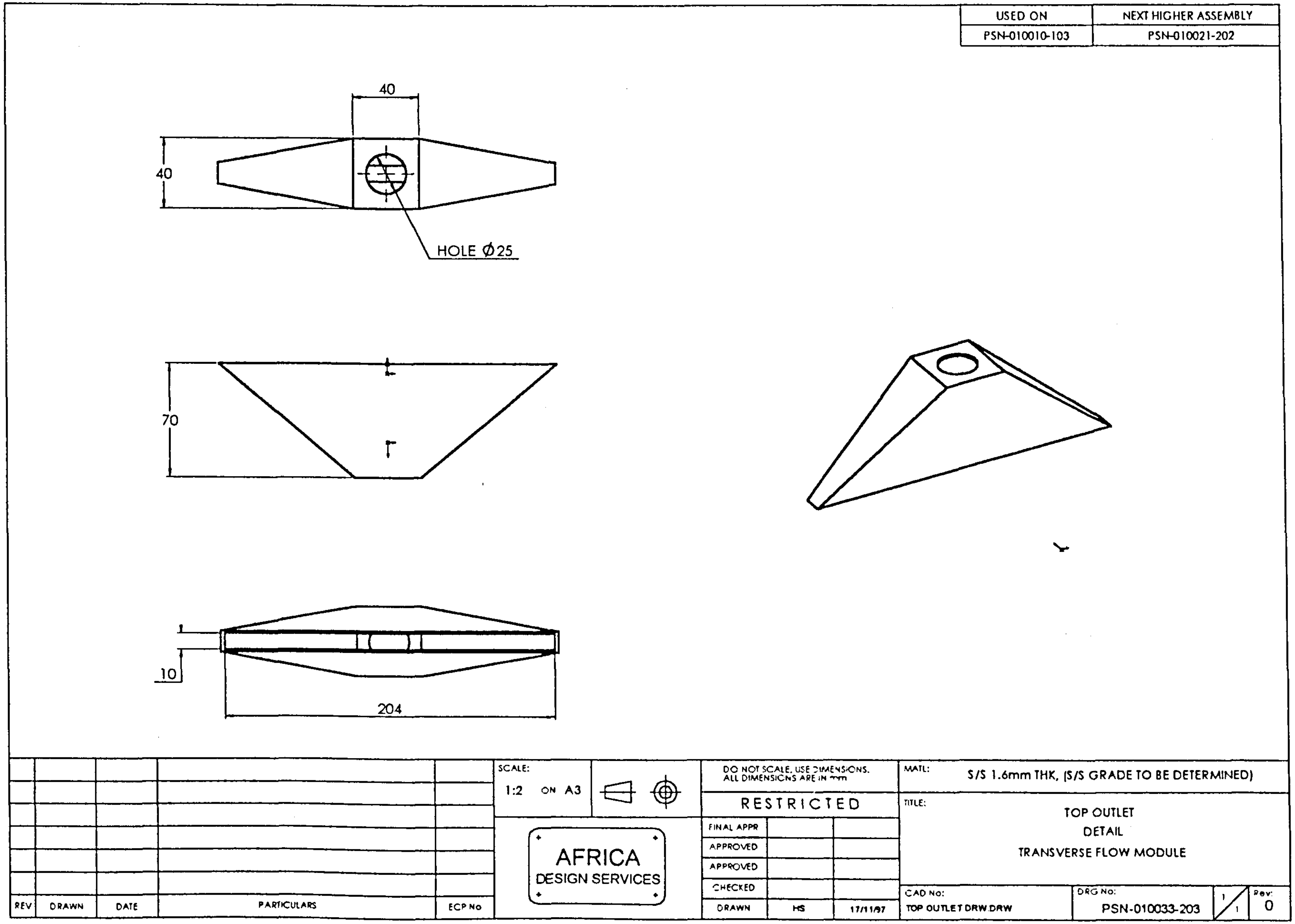


FIG A3 : Eng. detail dwg. inlet manifold s/p plate

FIG A4 : Eng. detail dwg. inlet manifold outlet



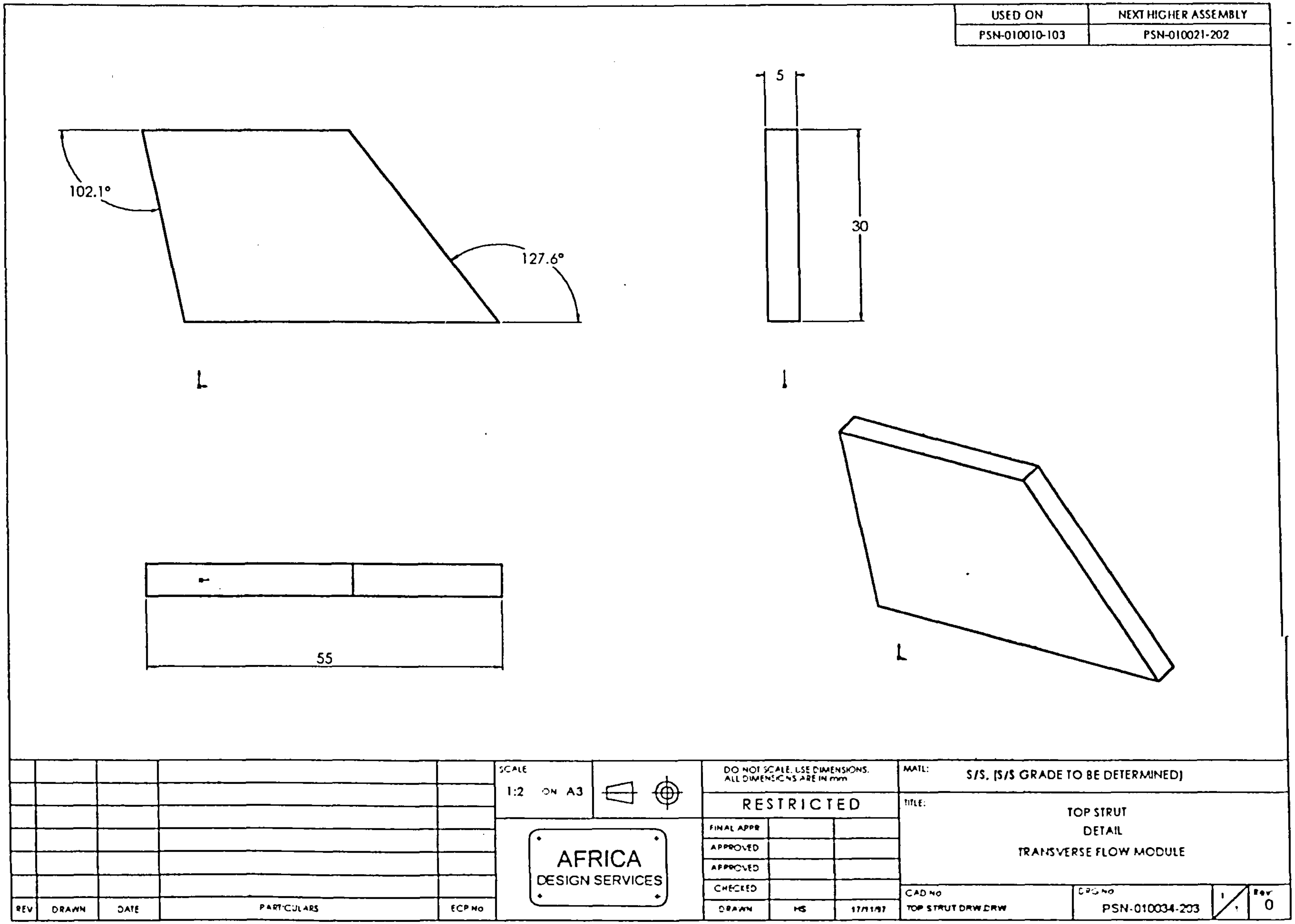


FIG A5 : Eng. detail dwg. inlet manifold strut

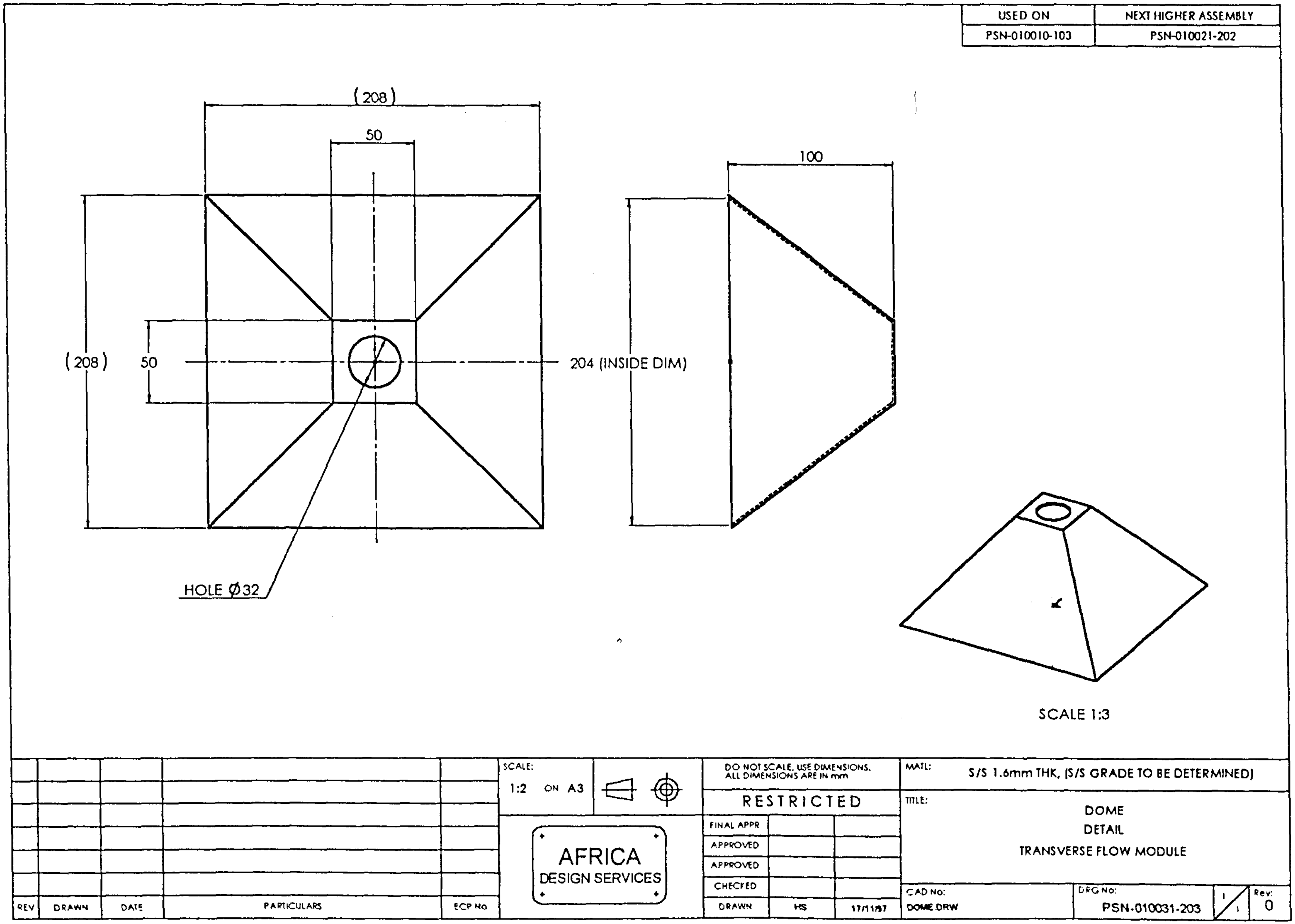


FIG A6 : Eng. detail dwg. inlet manifold dome

FIG A7 : Eng. manifold project breakdown