SOLAR POWER FOR REMOTE AREAS
CHEMICAL HEAT PIPES

PROGRESS REPORT
JULY 1979

PRESENTED BY
P O CARDEN

HEAD
ENERGY CONVERSION GROUP
DEPARTMENT OF ENGINEERING PHYSICS
THE AUSTRALIAN NATIONAL UNIVERSITY

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Major Contributors to this Report

P O Carden

O M Williams

ACKNOWLEDGEMENT: The work reported here has benefitted from the strong support given by the Head of the Department of Engineering Physics, Professor S Kaneff.

CONTENTS

1. SUMMARY

Project Title: Solar Power for Remote Areas - Chemical Heat Pipes

Organisation: The Australian National University, Department of Engineering Physics, Energy Conversion Group

Project Leader: P O Carden, ME, PhD

Objective: To investigate the concept of thermochemical energy transport (chemical heat pipes) particularly with regard to its application to the transport of energy from an array of solar collectors to a central generating station.

To examine in depth the application of the ammonia chemical heat pipe while keeping abreast of developments elsewhere in alternative chemical heat pipe systems. To develop in conjunction with industrial consultants a cost effective 10 MW_e solar power plant and to carry out all relevant theoretical and experimental studies.

To demonstrate an ammonia chemical heat pipe by constructing a 10 kw_t pilot plant.

Work Programme: In conjunction with our consultants Davy Pacific, further improve several aspects of the 10 MW_e design so as to reduce costs.

Construct a 10 kw pilot plant to demonstrate the ammonia chemical heat pipe.

Carry out an experimental programme to determine fundamental and operational aspects of the plant. Perform theoretical studies relevant to specific problems and thermochemical energy transport in general.

Perform comparative studies of different thermochemical systems.

Project Status: As required by NERDDC, the status of research in thermochemical energy transport in important centres throughout the world has been reported (ref 1). This area of research is growing in significance because of its application to nuclear energy utilisation as well as to solar energy. Distributed solar energy systems using chemical heat pipes show promise of being among the most cost effective methods for solar power generation especially for the larger plants. The work at the ANU on the ammonia chemical heat pipe appears to be the most advanced in this area of research.

Our consultants Davy Pacific have confirmed in their report (ref 2) that a 10 MW_e solar power plant using the ammonia chemical heat pipe is feasible and will be cost effective in the forseeable future.

An experimental programme has been defined and confirmed by Davy Pacific as being appropriate to the further development of the 10 MW_e plant. This experimental programme is based on a 10 kw_t demonstration ammonia chemical heat pipe the design of which has been completed and construction commenced.

A strong theoretical and experimental base for this work has been established.

2. INTRODUCTION

The work of the Energy Conversion Group this year has been aimed towards meeting the following objectives in collaboration with our consultants Davy Pacific:

1. Specify in some detail a workable solar power generation system for a remote township of the order of 10 MWe. The specification should assume advanced technology and the successful outcome of further research if thought necessary.
2. Prepare a system study addressing the question of energy flow under various conditions.
3. Determine the technical feasibility and the nature of hazards eg. those due to leakage.
4. Prepare an economic feasibility study.
5. Determine the cost of a small scale (10 kw) demonstration chemical heat pipe.
6. Identify the relation between the ANU research work and that proceeding in the USA and elsewhere.

To help meet these objectives a new staff appointment has been made. New laboratory space has been acquired through the assistance of the Research School of Physical Sciences.

<u>New Staff</u>: A technical officer was appointed in late March. However, the appointee was not able to obtain an assurance from the Public Service Board that he would be re-employed should his one year appointment with the ANU not be extended. He, therefore, declined the ANU offer. The post was readvertised in June and another appointment made soon afterwards: this time the offer was accepted.

<u>New Laboratory</u>: The Energy Conversion Group has moved to a larger neighbouring laboratory that has been refurbished. The move was initiated by the Director of the Research School of Physical Sciences and the cost of refurbishing has been borne by the School.

The new laboratory appears to contain sufficient space for a 10 kw chemical heat pipe demonstration.

3. WORLD STATUS OF THERMOCHEMICAL RESEARCH

Dr Carden and Dr Williams attended the ISES Conference in Atlanta during May-June 1979 and conferred with many research workers both at the conference and during visits to a number of relevant laboratories in the USA. Dr Carden also travelled to France and Germany. Consequently, the report attached hereto as ref 1 has been prepared. This report describes research and development activities proceeding in laboratories overseas which relate to the work being carried out in the Energy Conversion Group.

The major conclusions of the report are:

- There is a rapidly growing interest abroad in thermochemical energy transport.
- There is substantial evidence that systems based on distributed mirror collectors and thermochemical energy transport will be among the most cost effective for solar power generation, especially for large plants.
- The work at ANU appears to be the most advanced in the area of solar thermochemical energy transport.

4. 10 MWe FEASIBILITY STUDY

4.1 General Specification

In considering the form of an appropriate solar power generation system it is necessary to try to look forward 15 or 20 years from now, to anticipate what improvements might be made in this period to conventional methods of power generation for remote townships and to anticipate advances in other relevant technologies. Of paramount importance is the probable movement in fossil fuel prices relevant to the general level of inflation during this period.

We consider it probable that fossil fuel prices will rise sufficiently to force improvements in the already efficient diesel engine and also to cause a new look at the steam turbine which has the advantage of operating on less expensive fuel oil than diesolene. The efficiency of diesel power generation may be improved by adopting the marine technology whereby waste heat from the diesel engine is used to raise steam for a steam turbine. The combination of a gas turbine and waste heat steam turbine also promises high efficiency. Steam turbines themselves may be improved in efficiency by introducing multistaging which is now economical above 30 MW but which may well be economical for 10 MW in 15 to 20 years from now. It is considered that present moves towards automatic start-up of steam turbines will overcome an existing practical difficulty in their application to remote areas.

Thus the remote area scenario we envisage is one where the steam turbine has already appeared. We therefore see the first application of solar energy technology being in a hybrid power generation system where the minimum achievable solar fuel cost just equals the cost of conventional fuel. Such a minimum cost solar system will utilise a high proportion of the solar energy as it is collected and will not emphasise energy storage (which adds to cost). Nor will energy storage be essential to the hybrid system since this will be effectively provided by the conventional fuel.

The justification for employing chemical heat pipes would then depend largely on their advantage in energy transport within the field of collectors particularly as the size of the collector field increases in the megawatt range.

But the potential for energy storage remains a valuable feature for it stands ready to be called upon whenever the economics of the hybrid system dictates. The optimum amount of storage will depend on how much the conventional fuel price exceeds the solar fuel price.

These considerations and others related to the size of remote towns, the size of ammonia converters and likely advances in the underground storage of hydrogen have led us to adopt 10 MW_e as the size of the solar power generating plant.

Summarising then the general specification of the plant is as follows:

. size 10 MW_e

. designed for maximum instantaneous utilisation of solar energy: minimum storage

. hybrid with (advanced) fossil fuelled plant.

4.2 Consultants' Report

We present herewith a report prepared by our consultants Davy Pacific on the feasibility of the 10 MW_e solar power plant. This report, ref 2, is a very important first stage towards achieving our goal of defining and studying a system that will be competitive in approximately 15 years time. The report is based entirely on proven technology except for the collector system which is based on the research and development being conducted in the Energy Conversion Group and assumes small collectors (10 m^2). Even so the outcome is very encouraging. The estimated all-inclusive capital cost is just under 3000 $/kw (1979 Australian dollars) and the energy cost 15 ¢/kwhr assuming present costs for fuel landed at a sea port. Under comparable conditions diesel generated power would cost 7.5 ¢/kwhr. If we assume that a modest reduction in real capital cost of the solar generating plant will occur as a result of further research and development, break-even is likely to occur if the fuel price is 3 or 4 times the assumed price. This could occur in the future as a result of rises in the world market price of oil coupled with the cost of transporting fuel inland.

The first generation capital cost of 3000 $/kw is to be compared with the 10 year goal for reducing the cost of photovoltaic collectors, also 3000 $/kw but exclusive of installation costs and the cost of back up facilities, and the cost of the 10 MW Barstow power plant reputed to be quoted at 6000 $/kw. It is also to be compared with nuclear power now costing in excess of 1000 $/kw.

Although there is emerging evidence that distributed chemical solar generating systems will be cost competitive with other systems including the central receiver system (refer to reference 1), there is no clear evidence ultimately favouring any one of the several candidate chemical systems. Consequently we intend to extend our studies of alternative chemical systems using, as much as possible, data obtained from other workers. We hope these studies may continue in concurrence with our experimental work on the ammonia system. The advantage of the ammonia system is that working demonstrations can be built now free from the need to first develop new materials (for corrosion resistance for example) or specific catalysts (to avoid side reactions).

5. 10 kw DEMONSTRATION PLANT

The design of a 10 kw system has proceeded in collaboration with Davy Pacific. The objectives to be accomplished all relate to the 10 MW_e study:

- to perform measurements of fundamental parameters eg. heat transfer coefficients, space velocity and activation energy of both synthesiser and dissociation catalysts, and so provide data on the performance of system components especially those embodying novel features such as the converter (or synthesiser) and the focal dissociator;
- to provide operational experience and data on the performance of the system as a whole and on the methods of control; to enable elevation of basic system efficiencies;
- to provide a test bed for examining a number of candidate catalysts and materials;
- based on the above data to further refine and test the designs of the system and its components so as to optimise the recovered work with respect to cost in the 10 MW_e design.

The following work has been completed to date:

- design analysis of the pilot plant. The basic plant layout is shown in Figure 1;
- definition of the design, construction and experimental research programmes;
- engineering design of the 10 kwt ammonia dissociator (Figure 2) which is currently being constructed in the RSPhysS workshop;
- construction of gas and liquid circulation pumps;
- engineering design of the synthesiser pressure vessel (Figure 3). Inconel 601 tubing for the reactor pressure wall has been purchased;
- design analysis of the fluid and temperature control systems. This analysis is closely associated with the design of the system for extracting heat from the synthesiser vessel for which a novel design feature is being developed for maximising work recovery and simplifying the control problems;
- design, specification and costing of the ammonia storage and separator/gas storage tanks;
- overall cost analysis (including staff requirements) for design, construction and operation of the demonstration plant.

6. RECOMMENDED FUTURE PROGRAMME

We endorse the recommendations of our consultants detailed in ref 2 for a research and development programme based on a 10 kw_t demonstration thermochemical energy transfer loop. Our future programme includes building the demonstration loop and achieving the objectives outlined in Section 5.

Many specific component tests relevent to the 10 MW design will be included in this experimental programme: high pressure hose couplings, tube and pipe jointing systems, various types of continuous tubing and piping systems based on continuous tubing.

Specific designs of focal absorbers and heat exchangers will be developed and tested.

In parallel with this experimental programme we intend pursuing a comparative study of the candidate chemical systems for thermochemical energy transport.

The objective of this recommended programme is to develop a design for a demonstration solar power station of a size sufficient to justify thermochemical energy transport: approximately 1 MW_e.

Closely allied to this programme is our work on the underground storage of hydrogen-rich gas mixtures. It is becoming more apparent (see refs 3, 4) that it is both feasible and relatively cost effective to store hydrogen in aquifers. The expected losses (less than 2% pa) are such that the similar storage of nitrogen/hydrogen gas mixtures, at least for periods of several days, should be seriously considered.

The programme described here requires a moderate increase in staff as is shown in the accompanying Application for a Support Grant. Of particular importance is the funding of an academic post at the level of Senior Research Fellow for a period of at least three years. Any lesser period of support for staff and for the project as a whole would seriously impede the programme and would diminish our presently considerable potential for success.

7. PATENTS

Two provisional patent applications have arisen from the work this year

- O M Williams: a converter design optimised for conversion of the heat of formation to work.
- P O Carden: a work recovery system using a gas turbine operating directly in the synthesis gas stream.

Both of these patents are generally applicable in the industry involved in the synthesis of substances such as ammonia and methanol. They are relevant to the growing need to conserve energy.

8. PUBLICATIONS

The publications of the Energy Conversion Group are attached hereto.

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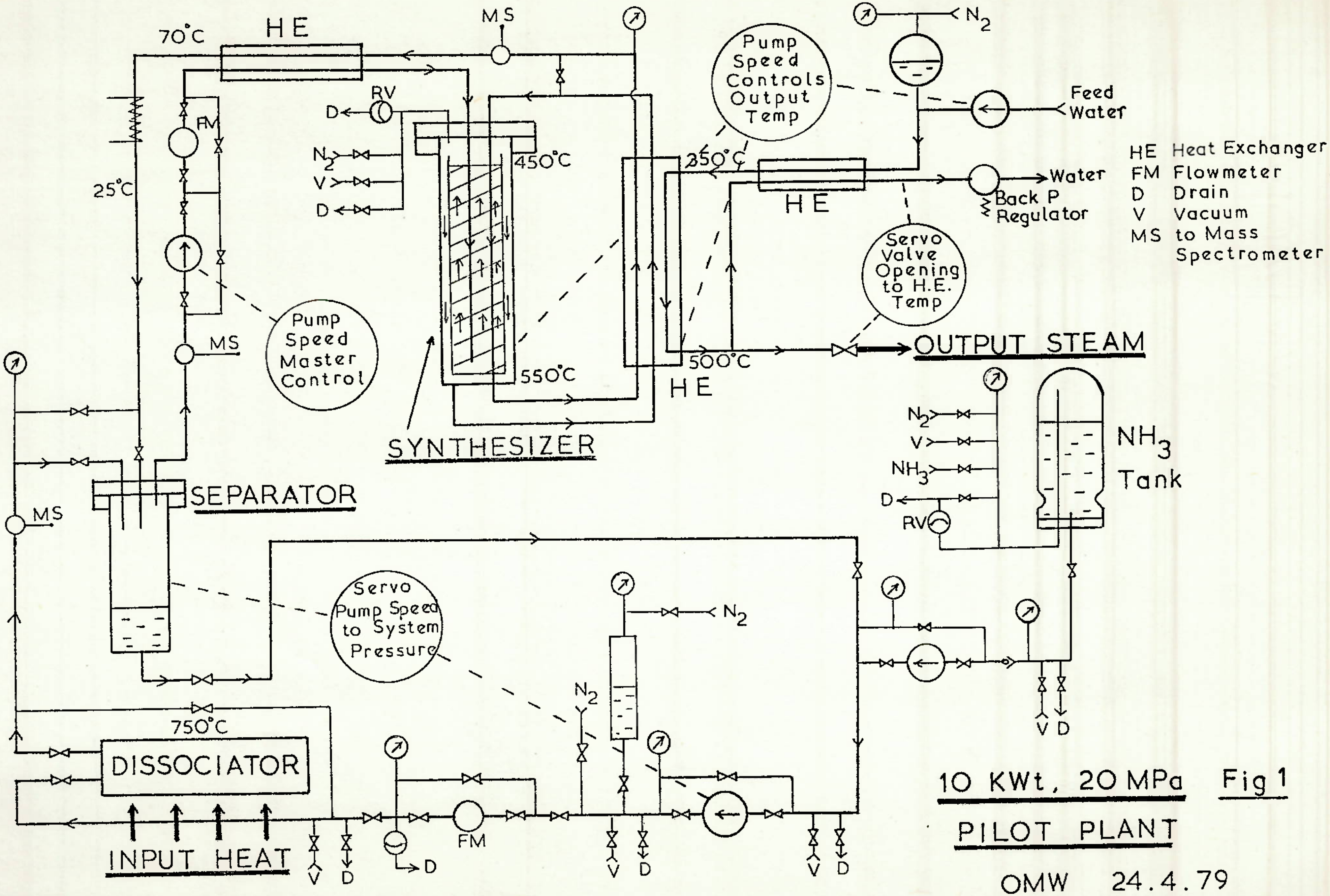

10 KWt, 20 MPa PILOT PLANT Fig 1

OMW 24.4.79

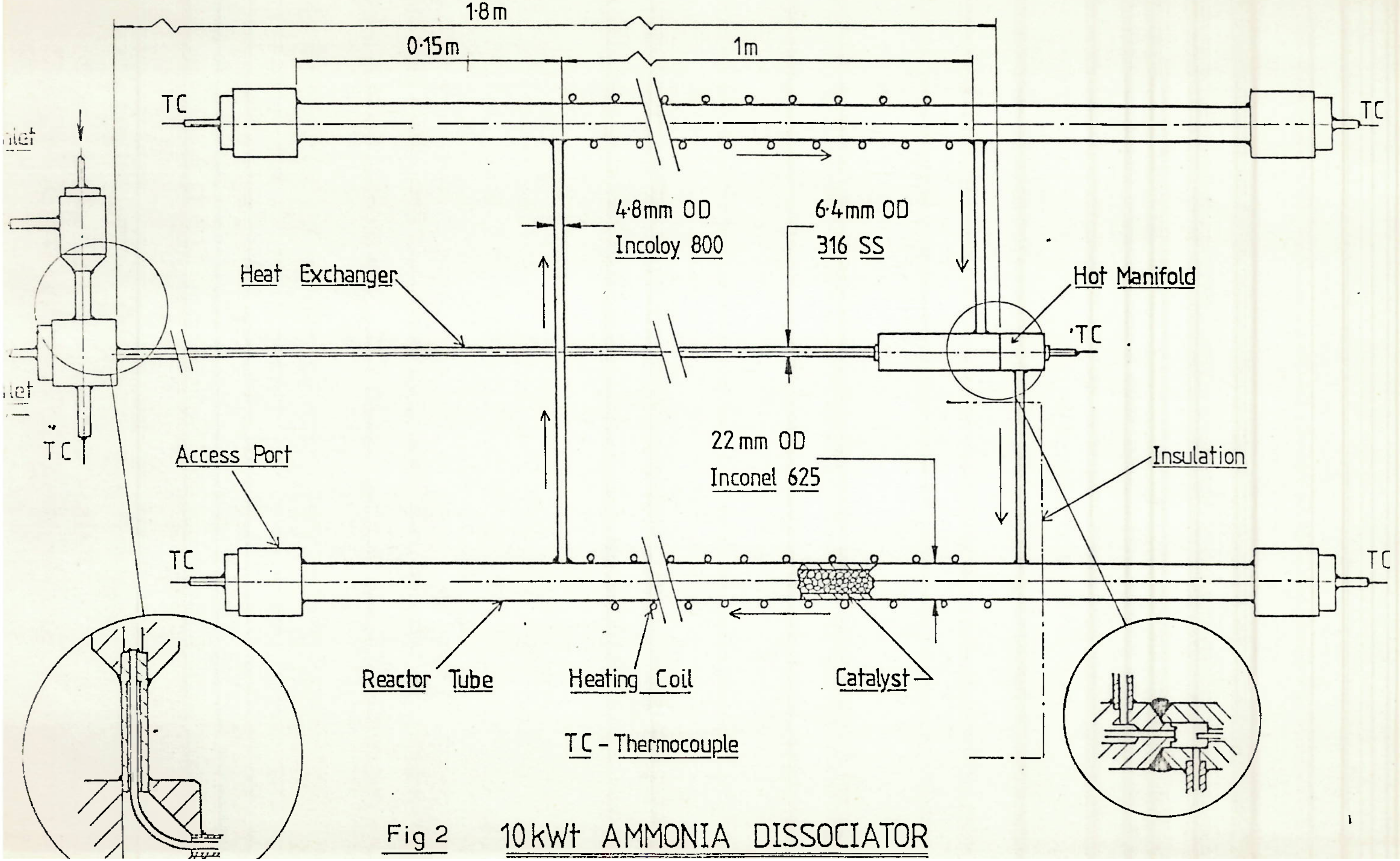

Fig 2 10 kWt AMMONIA DISSOCIATOR

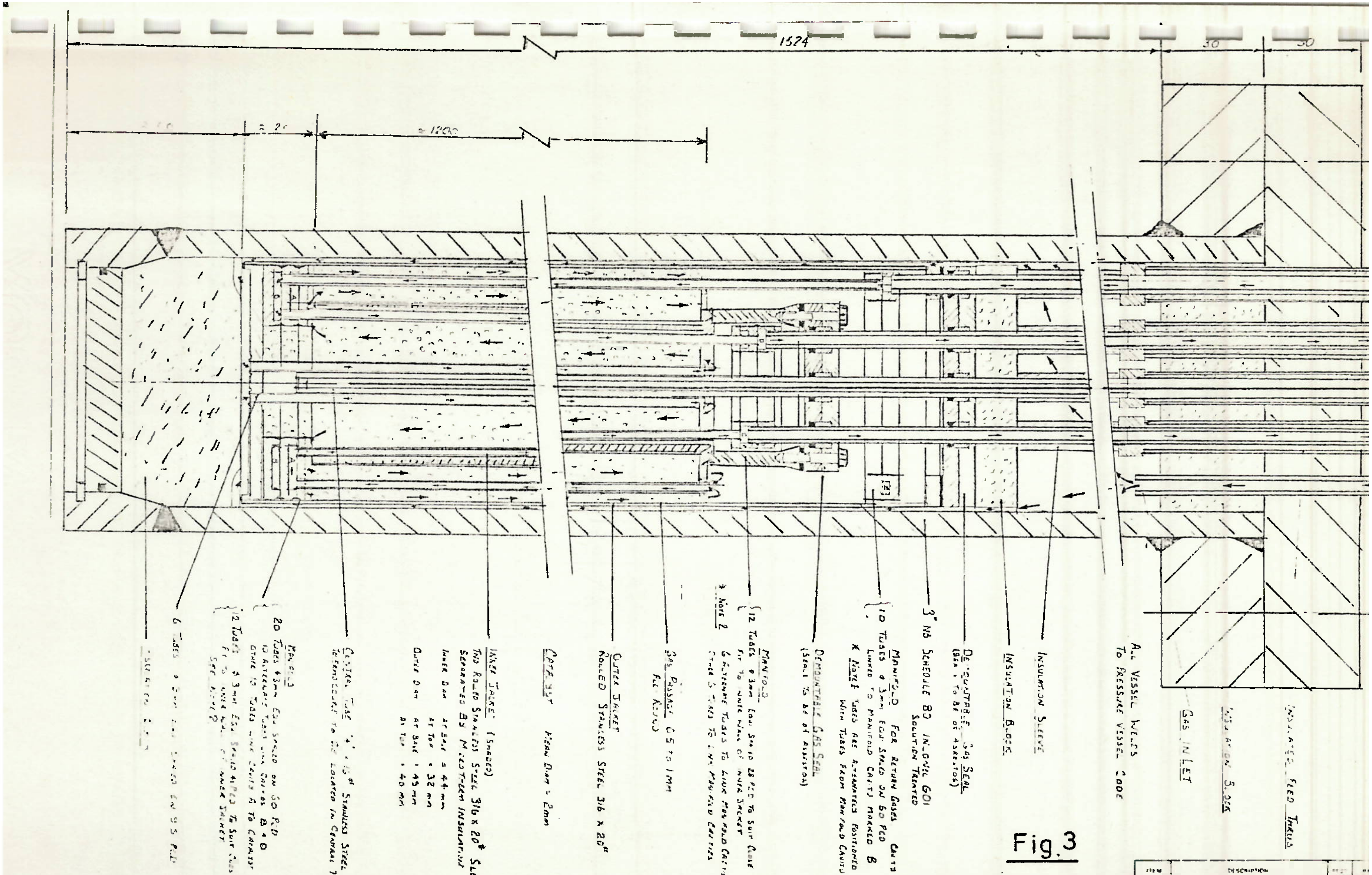

Fig.3

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Date	17-5-79
Material	St. Stl.
Specification	316

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10 kwt Ammonia Synthesizer
Design Concept Only.

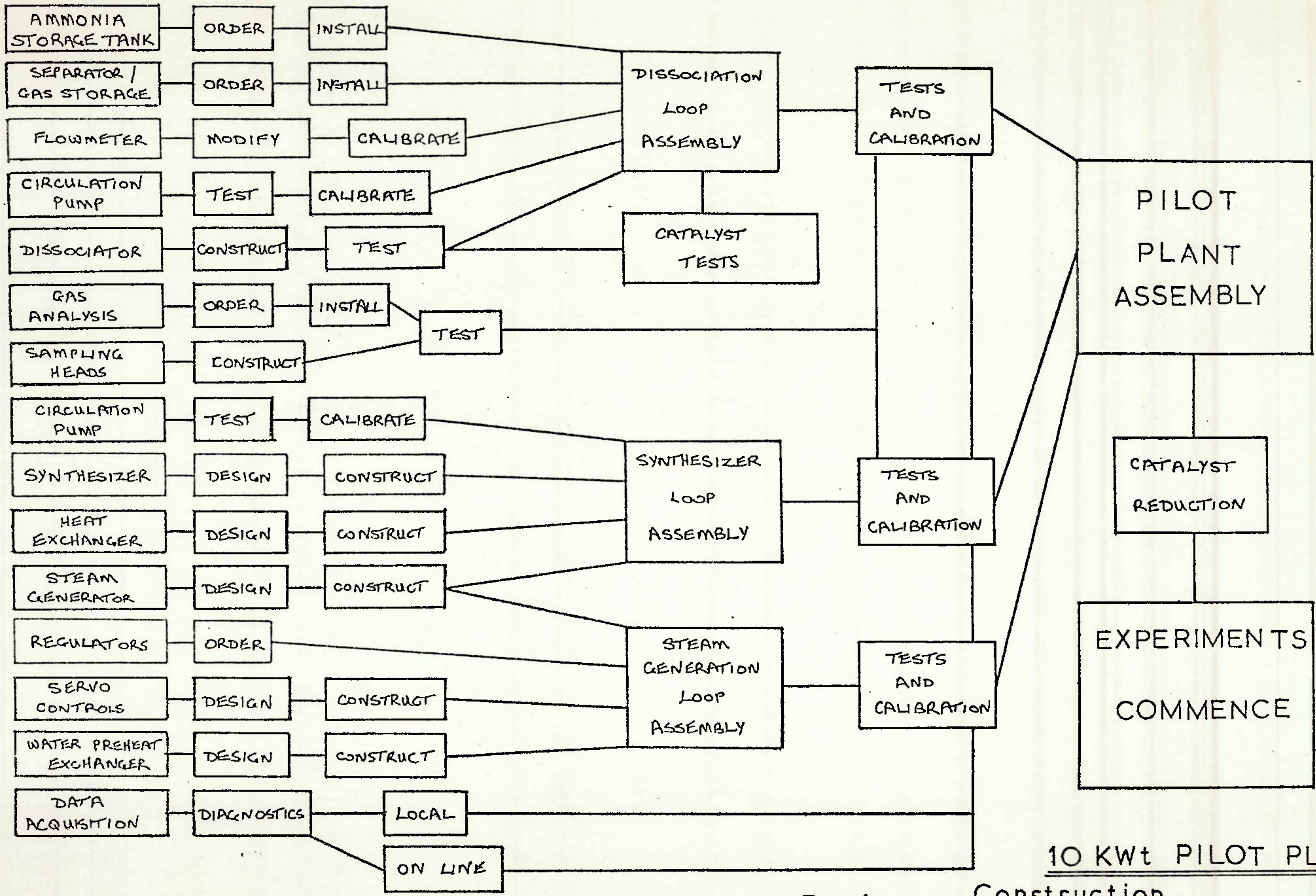
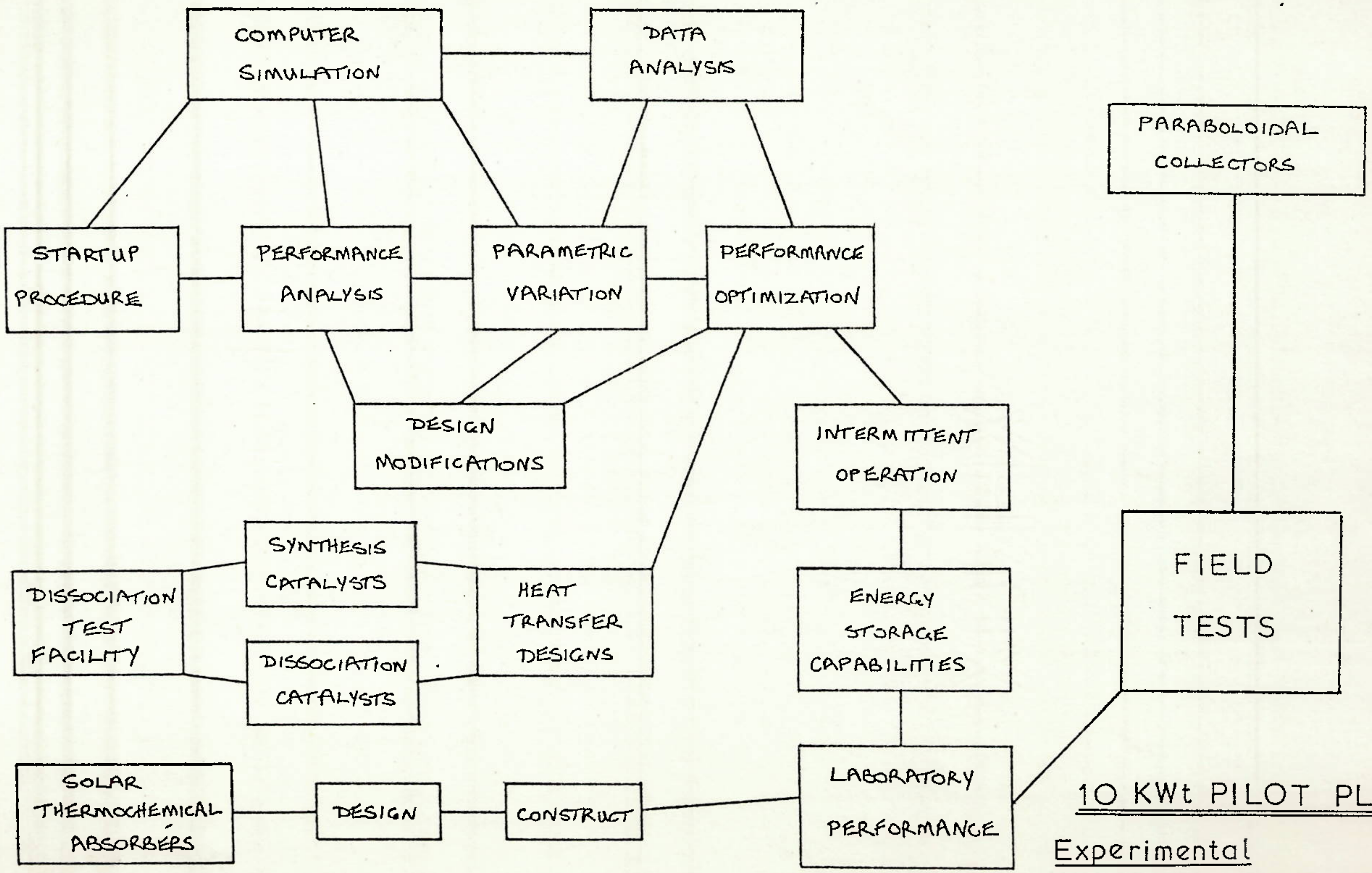


Fig.4

10 KWt PILOT PLANT

Construction Programme

OMW 26.4.79



10 KWt PILOT PLAN

Experimental Programme

Fig. 5

OMW 26.4.7