N. 27

# UNDERGROUND COAL GASIFICATION FIRST TRIAL IN THE FRAMEWORK OF A COMMUNITY COLLABORATION

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# TECHNICAL REPORT JANUARY 1994 - JUNE 1994


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**Summary**

The main activities during the period of this report were the surveying of the deviated injection well[IW1(ET4)], the initiation of the detailed engineering/design of the surface plant, including Gas Analysis and Data Acquisition/Control System Units, and additional engineering design for the recovery well[RW(ET5)].

The medium-radius deviated injection well[IW1(ET4)] was surveyed and logged to confirm the trajectory of the well and the locations of the points at which it crosses coal seam roof and floor.

The fibre optics installed along the tubing/liner were tested in place, tests prior to installation having also been conducted at YORK premises to confirm their suitability for the measurement of length and temperature profiles at high pressure and temperature conditions.

A contract to undertake Phase 2 of the Surface Plant Engineering was placed with SERELAND in May 1994 and invitations to tender for critical path items of plant were issued in June 1994. Contractors for the detailed design of Gas Analysis, and Data Acquisition/Control System Units were selected; the successful bidders being DUMEZ COPISA SISTEMAS(Gas Analysis Unit) and HONEYWELL(Data Acquisition/Control System Unit).

KAWASAKI THERMAL SYSTEMS, the manufacturers of THERMOCASE, the insulated tubing foreseen for the recovery well completion, informed of their intention to sell the company and that future availability of the product would be dependent on the plans of the new owners. With no definite date for sale of the company, an alternative recovery well completion was therefore formulated and evaluated.

Two projects continued in the supporting programme: INSTITUTO DE CARBOQUIMICA completed measurements on the pyrolysis and reactivity behaviour of the "El Tremedal" coal and began work on the modelling of reaction zone temperatures, and TU. DELFT in the Netherlands continued work on the thermomechanical behaviour of adjacent strata and modelling of the underground gasification process.

## 1. INTRODUCTION

This report is the fifth technical report of the Underground Coal Gasification project being conducted in North Teruel, Spain, with financial support under the EEC's THERMIE energy programme.

Accurate surveying of the trajectory of the deviated injection well[IW1(ET4)] and the locations at which it crosses the coal seam roof and floor are required to define the target for the recovery well[RW(ET5)] and to determine optimum CRIP locations for ignition/injection. This information was obtained via a gyro survey for accurate geometric location, and via a lithodensity log to detect traverse of coal seam roof and floor.

Tests of the fibre optics installed along the ET4 tubing/liner were realised in March 1994. Prior to these tests, the fibre optics were tested at YORK facilities to confirm applicability of the system at anticipated UCG conditions.

Final design of the recovery well[RW(ET5)] was delayed by the uncertainty surrounding the availability of THERMOCASE, the preferred insulated production tubing. The probable inability to procure this product in a time scale acceptable to project planning led to a decision to formulate/design alternative recovery well completion configurations.

Detailed engineering design of surface plant was initiated via a contract with SERELAND in May 1994, and the selection of contractors for the design and construction of the Gas Analysis and Data Acquisition/Control System Units.

## 2. DEVIATED INJECTION WELL[IW1(ET4)]

### 2.1 SURVEYING

Two types of logs/surveys were run in injection well[IW1(ET4)]. These were a neutron/lithodensity/gamma log to determine the trajectory locations of coal seam roof and floor boundaries for planning optimum CRIP locations, and a Gyro survey to obtain a more accurate geometric location of the trajectory of the well for recovery well[RW(ET5)] target definition.

A British Plaster Board(BPB) neutron/lithodensity/gamma log was run by ADARO in May 1994. The tool was able to accurately locate the boundaries (roof and floor) of the seam at the first crossing of the seam on each side of the 9.5/8" casing shoe, but not the re-entry point to the coal seam before the 6.5/8" in-seam liner shoe - the tool being unable to be run beyond 570 m MD because of the high inclination of the hole.

Having received a quotation for high accuracy gyro surveying of the trajectory with a SCHLUMBERGER GCT tool, the company subsequently advised that the tool would not in fact be available. After evaluation of other tools, a SCIENTIFIC DRILLING CONTROLS FINDER Gyro survey was run to Total Depth(6.5/8" shoe) in combination with SCHLUMBERGER CNL, GR and CCL in June 1994.

From the BPB neutron/lithodensity/gamma logs, and the SCHLUMBERGER CNL, GR and CCL, it was possible to confirm the first coal boundary crossings at approx. 510 m and 562.5 m MD, a shale inter-band also being identified at the top of the coal seam between 515.5 m and 519.5 m MD. The presence of two gamma peaks(from SCHLUMBERGER log) led to a more complicated interpretation/confirmation of the second entry inside the coal seam. Depending on gamma peak selection/interpretation, the re-entry inside the coal seam is located at approx. 618 m or 621 m MD. These two gamma peaks, observed for the first time at the coal seam floor(not identified in the previous exploratory wells), can be interpreted as a small coal seam floor discontinuity/irregularity, being amplified by the fact that the ET4 trajectory(in-seam drilling) is nearly parallel to the strata dip. Eventually, this discontinuity/irregularity will be checked/confirmed from future ET5 cores.

The overlap of the ellipses of uncertainty at TD of the surveys by MWD and Gyro demonstrates survey compatibility. The trajectory of injection well[IW1(ET4)] by the two surveys is shown in Figures 1a and 1b. Table 1 gives the reference ET4 trajectory based on the Gyro survey for the tubing/liner part of the well, and on the MWD survey for the open-hole interval of the well. Kick Off Point(KOP), 9.5/8" shoe and 6.5/8" shoe reference points are interpolated from adjacent survey points.

Table 2 gives a comparison of the MWD survey(BAKER INTEQ) and the Gyro survey(SCIENTIFIC DRILLING CONTROLS) interpolated by cubic spline at corresponding MWD measured depths. The comparison shows important differences in azimuth in the vertical interval of the well before KOP. This is explained by the poor azimuth accuracy of the MWD tool below 1° inclination. In the build and in-seam intervals, the azimuth measurements correlate well with difference below 1°. Below the vertical interval, two additional zones reveal differences greater than 1° azimuth: (i) the zone where the Downhole Assembly was tripped out/changed for a different bent housing angle and (ii) the zone after the 9.5/8" casing shoe where drilling was restarted with a different Downhole Assembly(12.1/4" $\Rightarrow$ 8.1/2" drilling phase).

The inclination measurements are generally in very good agreement throughout the complete trajectory with differences less than 0.5°. Only three zones of the trajectory give differences of inclination greater than 0.5°. These are: (i) the first zone of the build section where the Downhole Motor had difficulty to slide, (ii) the second zone of the build section where the Downhole Motor had difficulty to slide and the Downhole Assembly was tripped out/changed to remove the motor rear centraliser and (iii) the limestone zone where the Downhole Assembly was supposed to "bounce".

## 2.2 PERMEABILITY/WATER ACCEPTANCE TESTS

Water fall-off tests were carried out in injection well[IW1(ET4)] in order to obtain additional measurements of the permeability of the strata crossed in the open section of this well. The permeability of the section is important to estimate the flow requirement for water injection into injection well[IW1(ET4)] to achieve a balance of in-seam pressure with mud pressure during the drilling of the recovery well[RW(ET5)]. In the event of close approach of the recovery well[RW(ET5)] to the injection well[IW1(ET4)] during drilling, this balance should guard against the back flow of material. Permeability confirmation is also important for control in subsequent gasification phases.

The test was conducted simply by filling the well with water to well flange (1.72 m above GL) and measuring the decrease(fall-off) in water level in the well as a function of time. Basic equipment used was a water tank of 6000 litre capacity and a wire-line mounted KLL electrical probe for water level detection.

Two tests were conducted to confirm repeatability. The results of water level versus time are given in Figure 2. Permeability was calculated using the GILG-GAVARD formula for variable level, a method considered adequate for interpretation in low permeability strata.

The formula is:

$$k = 1.308\ d^2\ \Delta h\ /\ A\ h_m\ \Delta t$$

where

- $k$ = permeability of the strata(cm/s)
- $d$ = diameter of the well(m)
- $\Delta h$ = decrease in water level(m) in time interval $\Delta t$(min)
- $A$ = a coefficient that depends on the length(L) of the permeable zone crossed and the diameter of the slotted liner - in this case the open hole diameter(d)
- $h_m$ = average imposed hydrostatic head over the interval(m)

For a length of permeable zone higher than 6 m, the coefficient A is formulated as follows:

$$A = 1.032\ L + 30\ d$$

In order to apply the method, it is necessary to fix the length(L) of permeable zone in the formula. Because the open hole section of the injection well[IW(ET4)] crosses three different zones - impermeable limestone, very low permeable coal, and low permeable sand, three different values can be selected:

a) The length(L = 124.1 m) from 9.5/8" casing shoe to well TD(total open hole length)
b) The length(L = 69.1 m) of open hole in coal and sand
c) The length(L = 45.0 m) in sand only

Average permeability for the two tests are given in Table 3. The results for case c) are considered to be that of the sand, the results for cases a) and b) being averages depressed by the effects of the much lower permeability of limestone and coal.

The average permeability of the two tests on the basis of length of open hole in sand only, case c), is 15.5 mD. This value is in relatively good agreement with the 18 mD sand permeability determined from the Drill Stem Test(DST) conducted previously by GEOSERVICES in exploratory well ET1, and confirms that the sand has low permeability.

## 2.3 FIBRE OPTIC TESTS

Prior to their installation in the deviated injection well ET4, the fibre optic measurement system was tested in YORK and UKAEA(HARWELL) facilities, with the fibre optic line at pressure and temperature conditions similar to those expected in in-situ UCG conditions.

Three tests were conducted: (i) test of the temperature/length measurement capability of the Fibre Optic(FO) exposed to a direct flame at its extremity, (ii) test of the temperature/length measurement capability of the FO heated to 1100 °C and (iii) test of the temperature/length measurement capability of the FO pressurised to 200 bar.

All tests confirmed the capability/potentiality of the fibre optic system to measure temperature/length in the severe conditions of UCG. The main difficulty encountered by YORK was the filtration of a saturated signal emitted from the fibre optic end when exposed to very high temperatures(direct flame). This obliged YORK to develop/adapt their signal filtration procedure to UCG high temperature conditions. Figure 3 shows the comparison between the temperature measurement by thermocouple and FO, both sensors being installed in a temperature controlled oven.

The fibre optics and thermocouples, installed along the 7" tubing / 6.5/8" liner of ET4 in November 1993, were tested in place in March 1994. Figure 4 shows the temperature profile recorded from one single-ended fibre optic installed in ET4. The profile shows clearly the discontinuity provoked by the two splicings of the fibre and the end of the fibre.

To finalise the fibre optic installation in ET4, a manifold for nitrogen flow control inside the 1/8" Stainless Steel protection sheaths of the fibre optics was also installed/tested. High pressure nitrogen injection inside the annulus fibre optic - protective sheaths required the installation of a T-piece sealed with glue. Although this T-piece was previously tested at the UKAEA(HARWELL) laboratory, its sealing capability was not totally satisfactory during the field pressure tests and its design/installation will be revised/adapted for the installation of fibre optics in ET5 and ET2 prior to process operations.

# 3. <u>ENGINEERING</u>

## 3.1 WELLS[RW(ET5)] AND [IW2(ET6)] - DRILLING PROGRAMMES

The final trajectory of injection well[IW1(ET4)] and the revised CRIP locations require changes to be made to the target in-seam co-ordinates of the recovery well[RW(ET5)] and second injection well[IW2(ET6)]. Spud locations will not be affected but both wells will need to have greater displacements from their surface locations than initially planned. New well profiles were proposed for the wells and advice for planning and directional control was received from directional drilling companies. The wells will have "S" shaped(relief well) trajectories with relatively short horizontal displacements from spud locations. The revised trajectories should not lead to a need for different directional drilling techniques and costs should not be affected, the wells having required directional control in the original plan.

## 3.2 RECOVERY WELL[RW(ET5)] - COMPLETION PROGRAMME

In April 1994, KAWASAKI THERMAL SYSTEMS, the manufacturers of the preferred insulated tubing THERMOCASE for this well, informed of their intention to sell the company and that future availability of the product would be dependent on the plans of the new owners. No definite date was given for sale of the company and a programme of design/analysis therefore began on alternative completion configurations.

The proposed non-THERMOCASE configuration is shown in Figure 5. In this arrangement, the proprietary THERMOCASE casing is in effect replaced by two concentric tubing strings, whose annulus provides insulation for the product gas. During operations, a small flow of nitrogen would be passed through the annulus to prevent product gas back-flow entering the annulus.

In order to obtain a qualitative estimate of the insulation performance of the configuration, a simulation analysis of the system will be carried out by the UNIVERSITY OF LOUVAIN-LA-NEUVE. The objective of this analysis is to determine the ability of the system to maintain product gas in the gaseous phase along the complete length of the well.

Geometric specifications and materials requirements for this alternative completion arrangement were formulated, well-head design was initiated, and the ability to install thermocouples and fibre optics for temperature measurement was analysed in detail. Extensive enquiries were made to investigate the availability of materials and the ability to manufacture special alloy components to the required specifications.

An inability to order THERMOCASE beyond August 1994 would have important repercussions on programme planning and costs. A decision to proceed with the procurement of materials for the alternative recovery well completion will be taken in August 1994 if the ability to obtain THERMOCASE is still uncertain at that time.

## 3.3 SURFACE PLANT ENGINEERING

Invitations to Tender for Phases 2 and 3 of the Surface Plant Engineering were issued in January 1994, with the intention to award a contract for Phase 2, with Phase 3 as an extension.

The engineering of the Gas Analysis and Data Acquisition/Control System Units is outside the capability of general engineering contractors. For this reason it was decided that contracts for the design and construction of these

Units would be managed directly by UGE as separate contracts outside the scope of the main contract for Surface Plant Engineering.

Invitations to Tender for the detailed design/engineering of the Surface Plant were issued to the following companies:

ECOLAIRE
FOSTER WHEELER
JOHN BROWN SENER
SERELAND
TECPLANT INGEST

FOSTER WHEELER declined to tender. Tenders were analysed and a contract for Phase 2 was placed with SERELAND in April 1994.

First issue drawings have been produced of general plot and key plans, the process diagram, and P & ID's for feed systems, process wells, decompression stages and utilities. Tender enquiries have been formulated for the cryogenic units, gas combustor and flare, heat exchangers, boiler and dosing pumps. Instrumentation and Control Data Specification for tender enquiries are in preparation.

It is expected that Phase 2 will be completed late 1994 - early 1995. This will be followed by the procurement and installation of plant and equipment (Phase 3), with commencement of gasifier operations projected for Summer 1995. SERELAND were advised that there could be a delay between Phases 2 and 3 in the event of long procurement periods for items of well completion equipment. Orders for the procurement of surface plant materials and equipment in Phase 3 will be able to be made independently of drilling operations but the construction of surface plant in well areas must await the completion of drilling to avoid a conflict of activities.

A contract was placed with the electricity distribution company ERSA to install an electrical supply line to provide the required level of power for the trial. Permitting for the installation of pylons and the line is underway and the installation will be effected in Autumn 1994.

## 3.4 PRODUCT GAS ANALYSIS UNIT

Information on the composition of the product gas is necessary for process control via analysis of gasifier performance and efficiency. The Gas Analysis Unit is required to provide continuous analytical composition of process gas streams during the different phases of operation.

The design of the Unit is not straightforward because the composition of the gas cannot be predicted accurately and will vary greatly between process phases. A further complicating factor is that the water/liquid content of the gas streams could be very high in particular process phases, requiring cut-off protection to prevent the entry of liquid to analysers. Corrosion protection must also be given special attention because of the high hydrogen sulphide concentrations expected as a result of the high sulphur content of the coal.

The requirements of gaseous and liquid analysis were specified and Invitations to Tender for the design and construction of the Gas Analysis Unit were issued to the following companies in May 1994:

COMSIP
DUMEZ COPISA SISTEMAS
MASA
MIESA
SAINCO

DUMEZ COPISA SISTEMAS was selected for this detailed design /engineering of the Gas Analysis Unit contract(Phase 1). The contract covers specifications of equipment, safety and a cost/price estimate for Phase 2, as a turnkey contract for the procurement of equipment and construction of the complete Unit.

## 3.5 DATA ACQUISITION/CONTROL SYSTEM UNIT

The process phases of the trial will be managed via control of the injected flows, reactor back pressure and pressure let-down, product gas composition, and the recovery well bottom hole temperature. The Data Acquisition System will acquire, store, process, visualise and/or print data from a large number of surface and subsurface instruments for operational monitoring. The Data Control System will manage a group of controllers, strategic point alarms and safety actions.

The requirements of the Data Acquisition/Control System Unit were specified and Invitations to Tender for the design and construction of the Unit were issued to the following companies in May 1994:

COMSIP
DUMEZ COPISA SISTEMAS
FISHER & PORTER
HARTMANN & BRAUN
IST
PD&C
SILICON
COSINOR
ELIOP
FISHER-ROSEMOUNT
HONEYWELL
LINEAS ELECTRONICAS
SCAP EUROPA

After appraisal of quotations, HONEYWELL was selected for the detailed design/engineering of the Data Acquisition and Control System(Phase 1). Whilst other tender selections were made only on the basis of the technical/commercial merits of the offers, the selection of the Data Acquisition/Control System Unit supplier was also controlled by a decision on the hardware/software architecture of the System.

Basically two architectures were proposed by the companies invited to tender: (i) PC based architecture with a proprietary Data Base Manager implemented on a MS-DOS/WINDOWS or a UNIX Operating System and (ii) Workstation based architecture with a proprietary or commercial Data Base Manager implemented on a UNIX Operating System.

For the small to intermediate data acquisition and control application involved, it was recognised that the HONEYWELL PC based architecture using a proprietary Data Base Manager implemented on a UNIX Operating System was the best compromise between cost and flexibility of utilisation.

## 4. SUPPORTING PROGRAMME

The work at INSTITUTO DE CARBOQUIMICA covering the laboratory measurement of pyrolysis of the "El Tremedal" coal was completed. This work provides valuable information on the pyrolysis behaviour of the coal for process planning, and results interpretation and analysis. A preliminary report on the pyrolysis behaviour was received.

The layout of the fixed bed reactor system used for the pyrolysis studies is shown in Figure 6. Pyrolysis products were obtained and analysed at three pressures (5,15, 25 bar) and at five temperatures (400, 500, 600, 700, 800 $^{o}C$) at a heating rate of 10 C deg. / min, and at 30 minutes isothermal condition at final pyrolysis temperature. The tests were conducted without carrier gas in order to maximise the residence time of volatiles within the coal bed.

For each pressure/temperature condition, the pyrolysis behaviour was evaluated in terms of gas, tar, char and water yield, gas composition, char analysis, and sulphur distribution in the pyrolysis products. The results of the tests are shown in Figures 7 to 10. Empirical correlation of char, gas, water and tar yield as a function of temperature and pressure are shown in Table 4. Figure 11 shows the comparison between experimental pyrolysis product data and values predicted by empirical correlation.

In general, the pyrolysis behaviour of the "El Tremedal" sub-bituminous C coal/lignite was considered to be typical of coals from the Teruel basin. The most significant result for the UCG process interpretation is the identification of a strong influence of pressure on the sulphur distribution in pyrolysis products. In Figure 10, it can be seen that almost 100 % of the sulphur is maintained in the char up to 600 °C, for pressures in excess of 25 bar.

The final phase of the work being conducted by INSTITUTO DE CARBOQUIMICA, the prediction of maximum in-seam temperatures in the combustion zone as a function of operating conditions, is underway and a report on the study of coal/char reactivities is in preparation.

Work on UCG process behaviour by TU. DELFT continued. Workers from the University visited UGE in June 1994 to obtain rock samples from the roof strata overlying a coal seam at a nearby open-cast mine at Foz Calanda. This roof strata is considered to be comparable to that overlying the "El Tremedal" coal and will be used for the studies of thermomechanical stability of the overburden to the UCG cavity.

A meeting of the Scientific and Technical Advisory Group was held in April 1994. Alternative recovery well design/completion was discussed in detail at this meeting, and preliminary results on the pyrolysis measurements and analysis was presented by CARBOQUIMICA.

## 5. PROJECT DIRECTION

### 5.1 ADMINISTRATION

Two additional staff were recruited in February 1994 for activities in Data Acquisition/Control and Field Co-ordination. The vacancy in Process Control/ Analysis remains unfilled. Current complement of the team is 13 full-time personnel.

### 5.2 PROBLEMS/DIFFICULTIES

The most important technical problem was the decision of KAWASAKI THERMAL SYSTEMS to sell the company, with the resultant uncertainty regarding the availability of THERMOCASE insulating casing for recovery well [ RW(ET5)].

### 5.3 CHANGES IN TECHNICAL STRATEGY

A decision to proceed with the alternative recovery well completion design will be taken in August 1994 if the ability to obtain THERMOCASE is still uncertain at that time.

### 5.4 FUTURE WORK

The two remaining process wells[RW(ET5)] and [IW2(ET6)] will be drilled during the second half of the year. Procurement of special alloy tubing and other components for well completions will begin in August 1994.

Contracts for the detailed design/engineering of the Data Acquisition/Control System Unit and the Gas Sampling/Analysis Unit will be placed in July/August 1994. Invitations to Tender for important parts(cryogenic plant, gas combustor and flare plant, dosing pumps, ...) of the surface plant will be issued.

Work on reaction temperature modelling at INSTITUTO DE CARBOQUIMICA should be completed before end 1994.

## 5.5 CONFERENCES, PUBLICATIONS AND REPORTS

- "Drilling of Medium-radius Deviated Well for Underground Coal Gasification at Great Depth" by A.C. BAILEY, M. MOSTADE and A. OBIS. Paper presented at the Ninth International Mining and Metallurgy Congress, León(Spain), 24-28 May 1994.

- "Permeability Test in Deviated Injection Well[IW1(ET4)]"(97/IN/95/S) Internal report prepared by C. BARAT

- "Pyrolysis study of the El Tremedal Coal - Preliminary Results" Preliminary Report prepared by INSTITUTO DE CARBOQUIMICA.

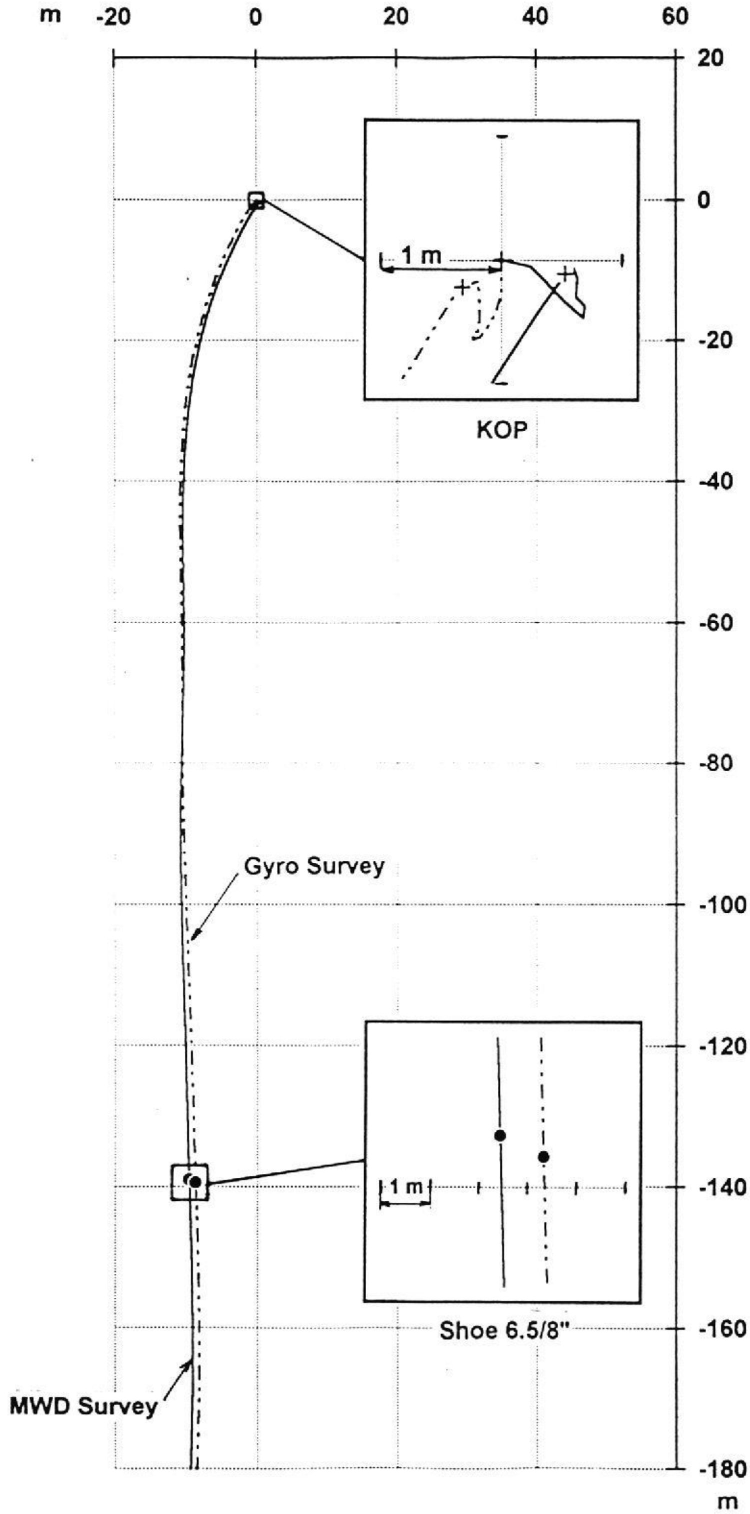


**Figure 1a . Comparison of ET4 MWD and Gyro Surveys (Horizontal Section)**

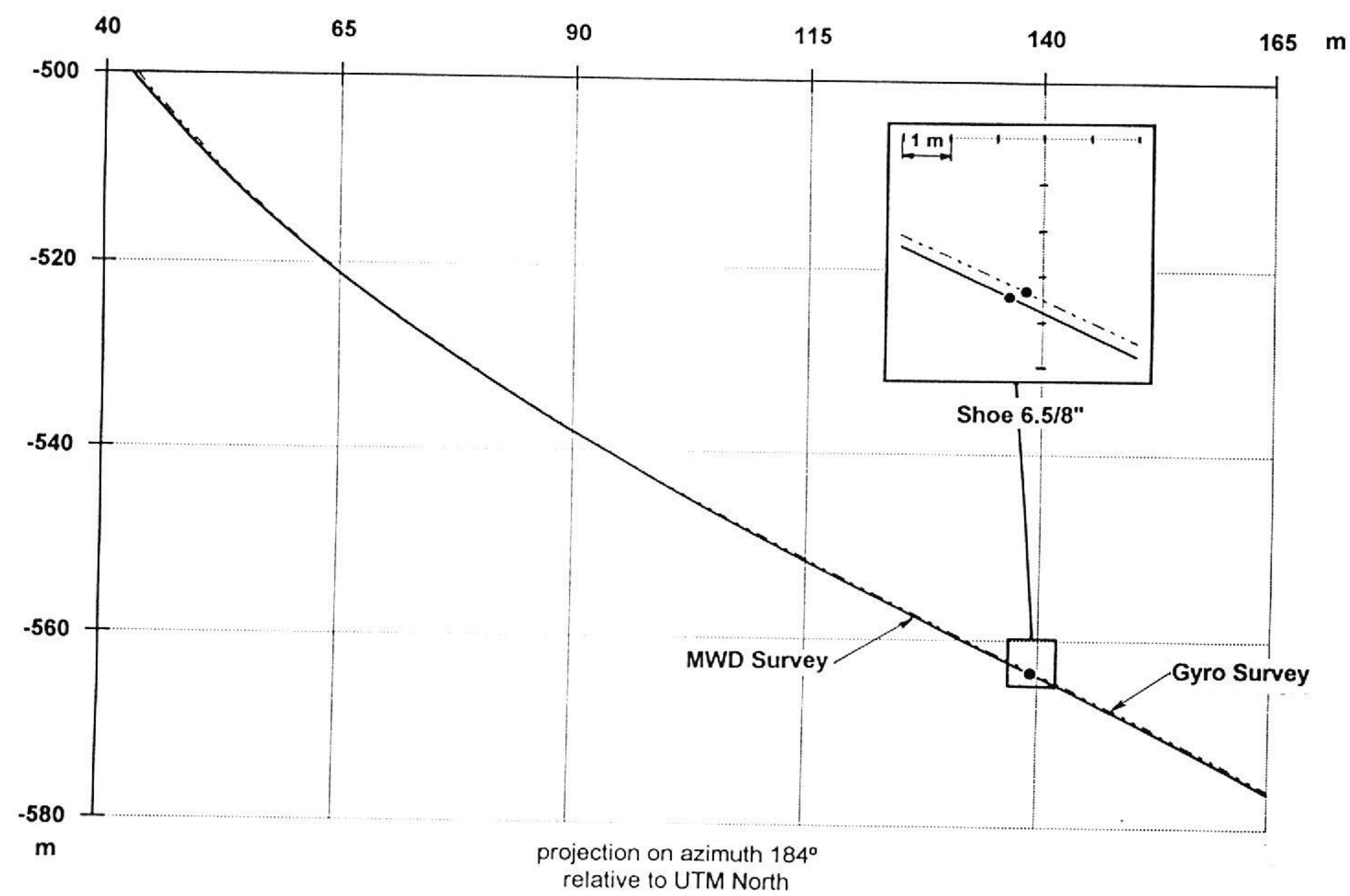


**Figure 1b . Comparison of ET4 MWD and Gyro Surveys**
**(Vertical Section - In-seam Interval)**

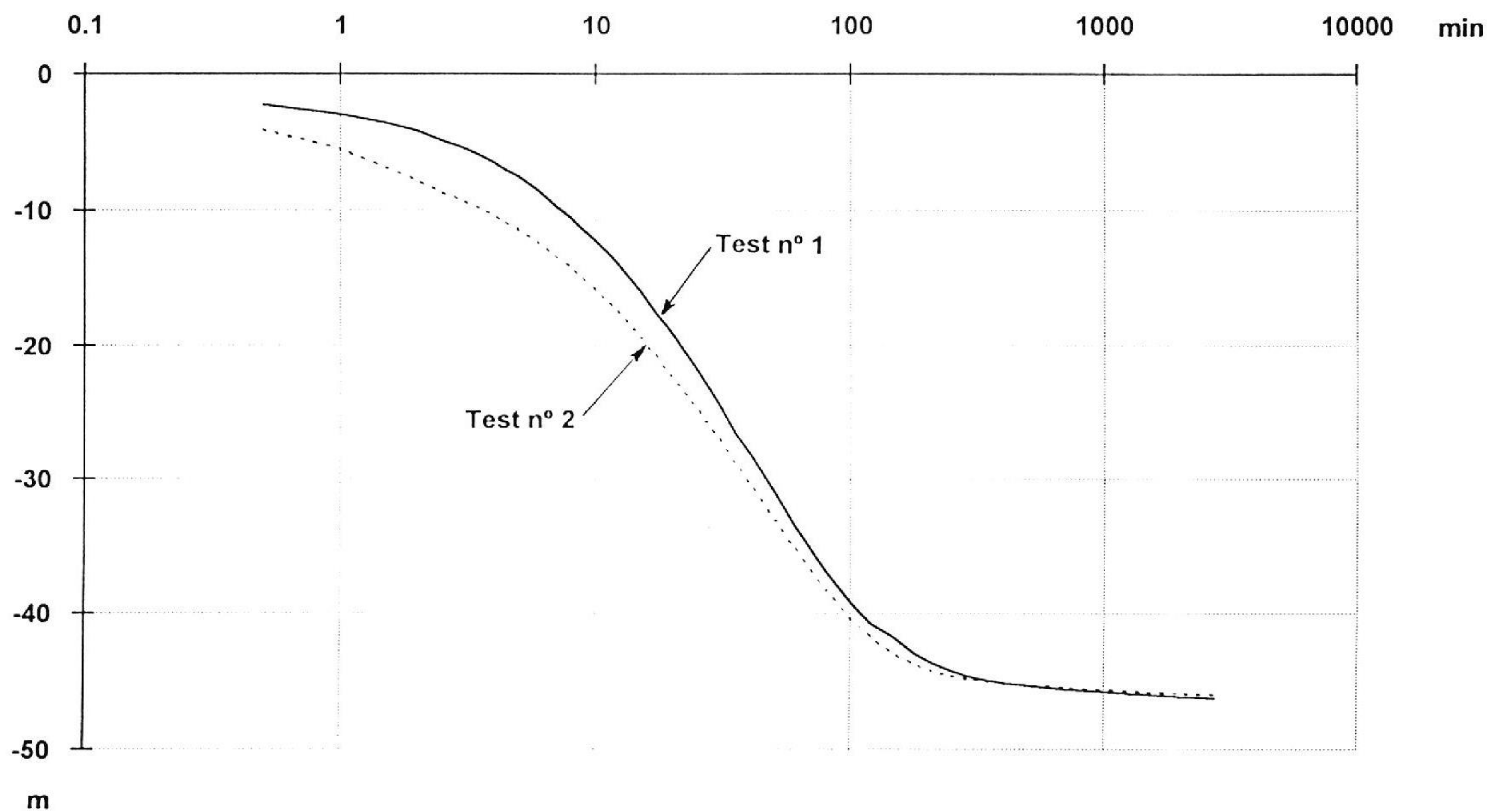


Figure 2 . ET4 Water Fall-off Tests (water level versus time)

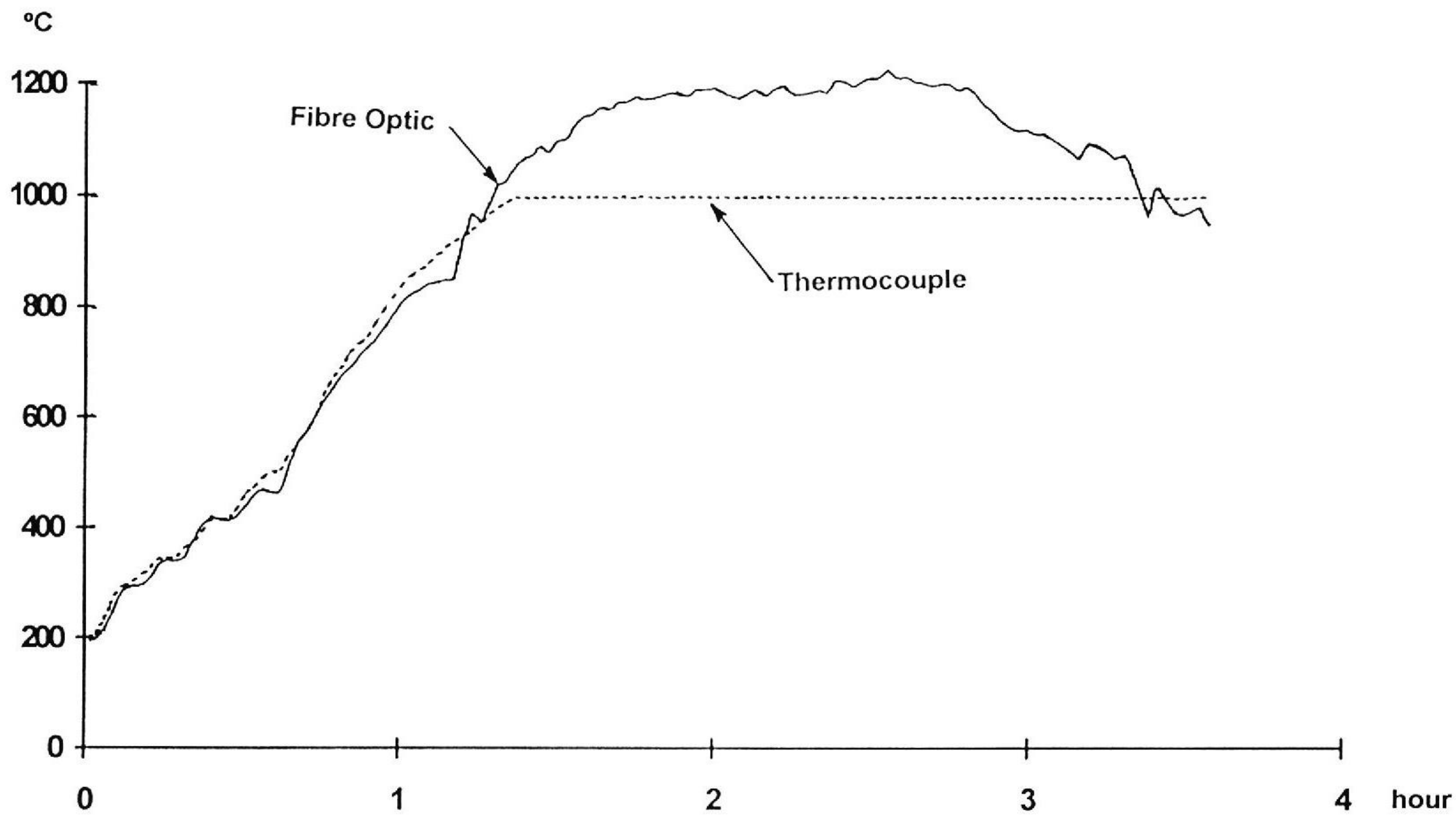


**Figure 3 . Comparison between Thermocouple and Fibre Optic Measurements (temperatures versus time - temperature controlled oven)**

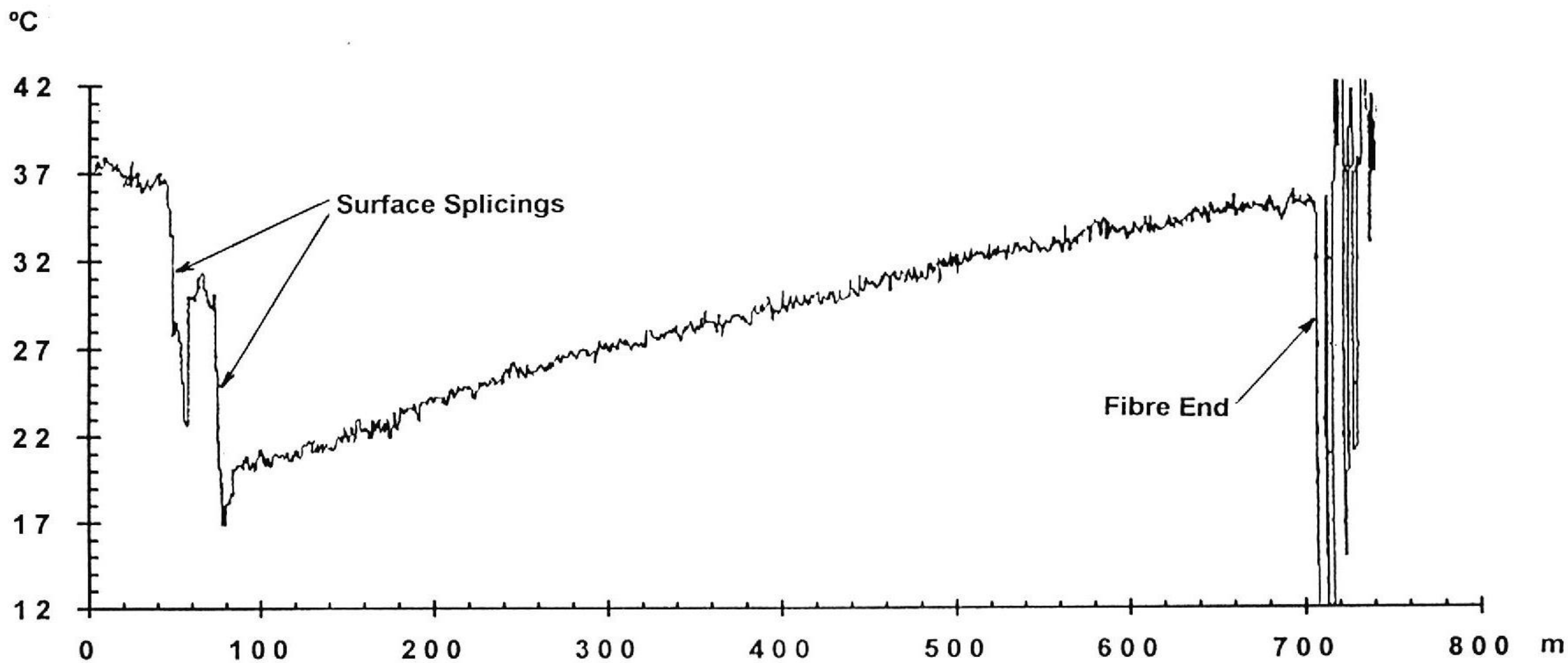


Figure 4 . Temperature Profile along the Single-ended Fibre Optic Cable installed in ET4

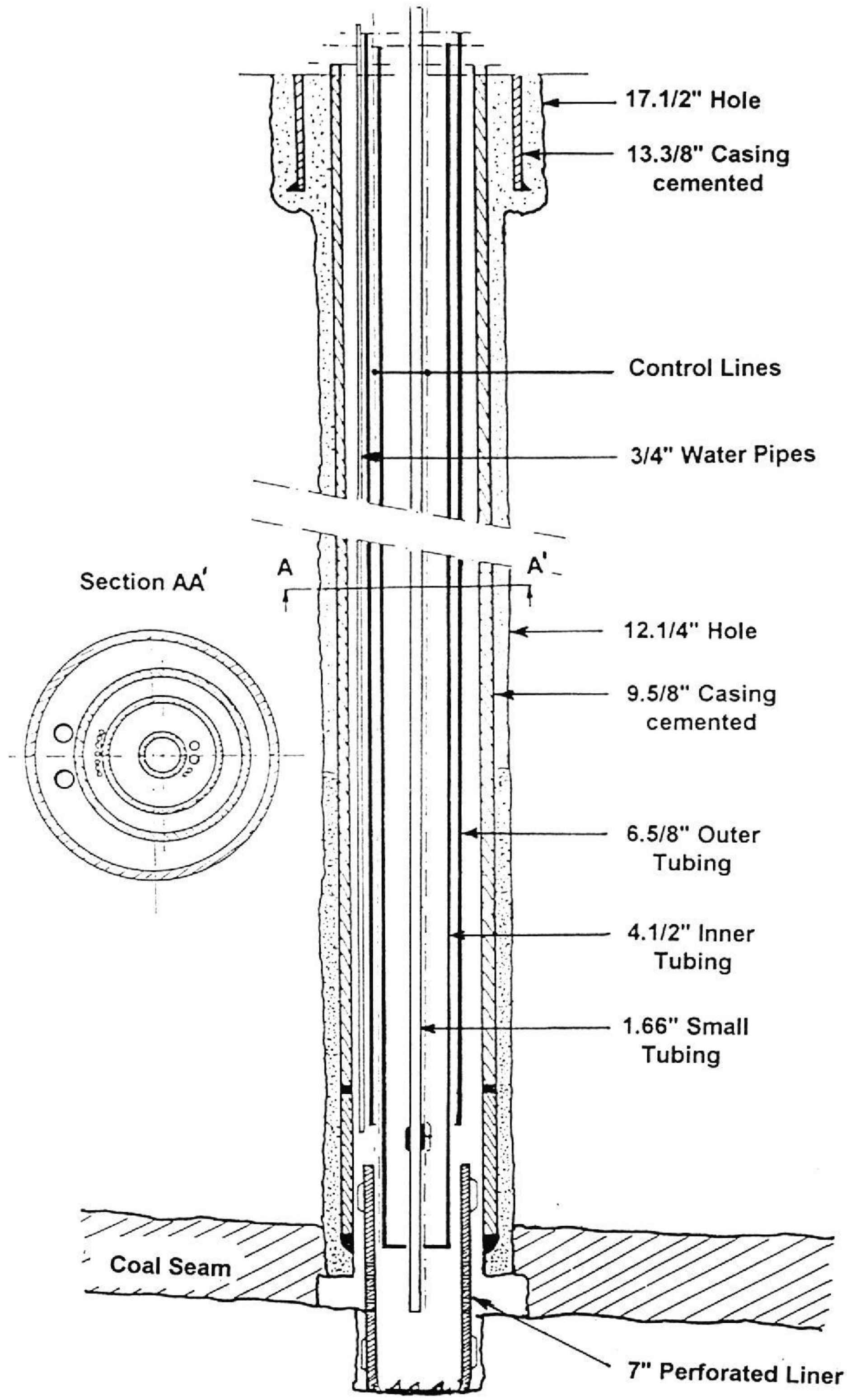


**Figure 5 . Proposed Double-annulus Configuration for Recovery Well[RW(ET5)]**

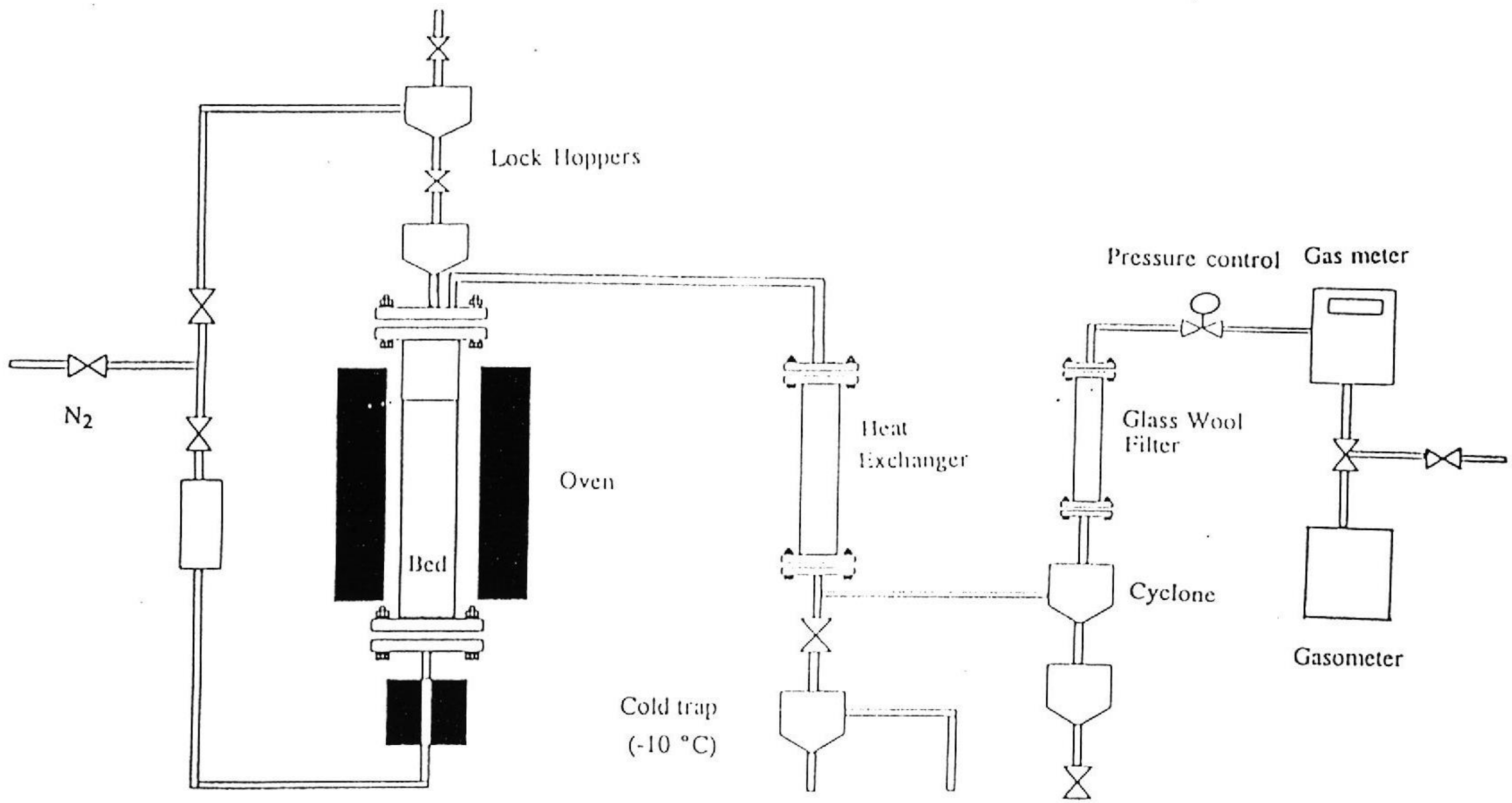


**Figure 6 . Layout of the Fixed Bed Reactor used during the Pyrolysis Tests**

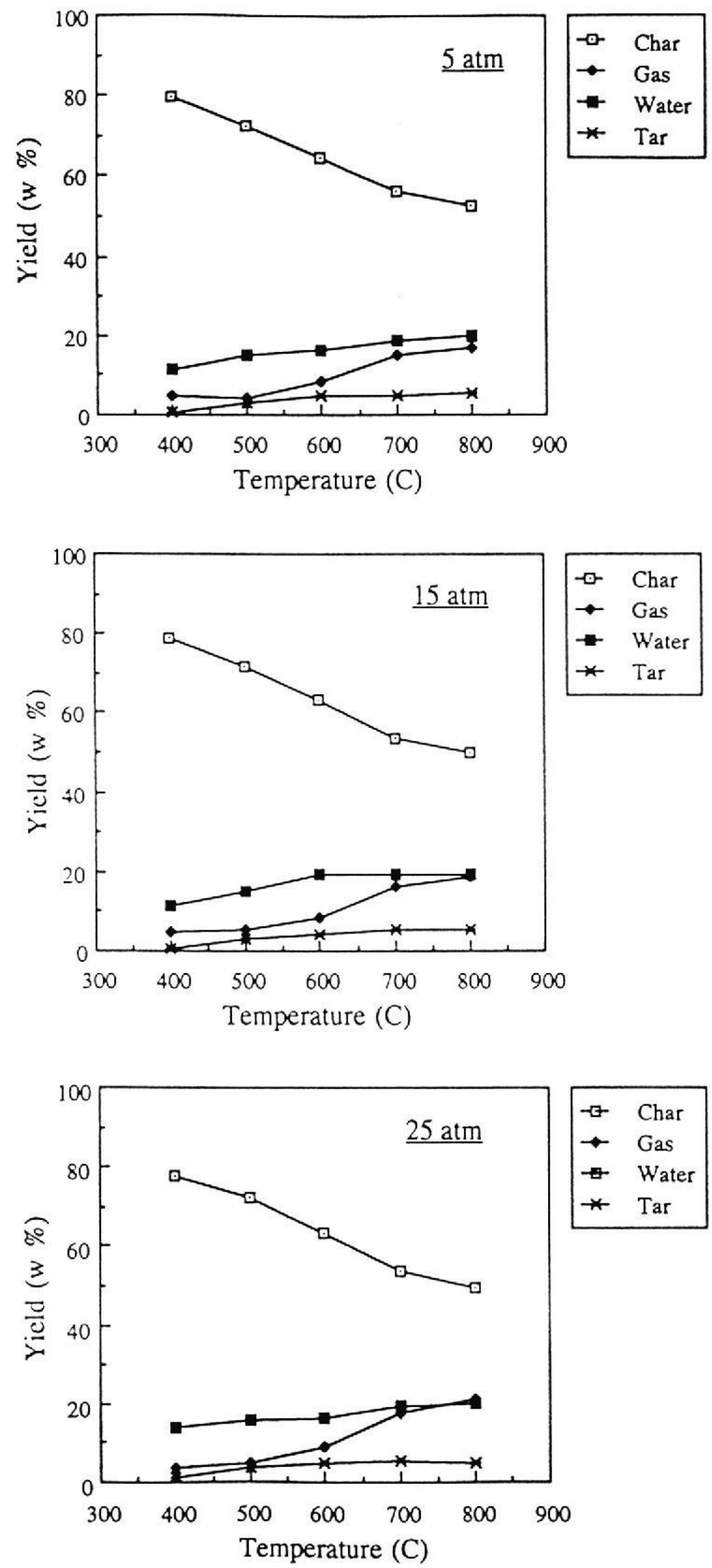


**Figure 7 . Effect of Temperature on Pyrolysis Product Distribution**

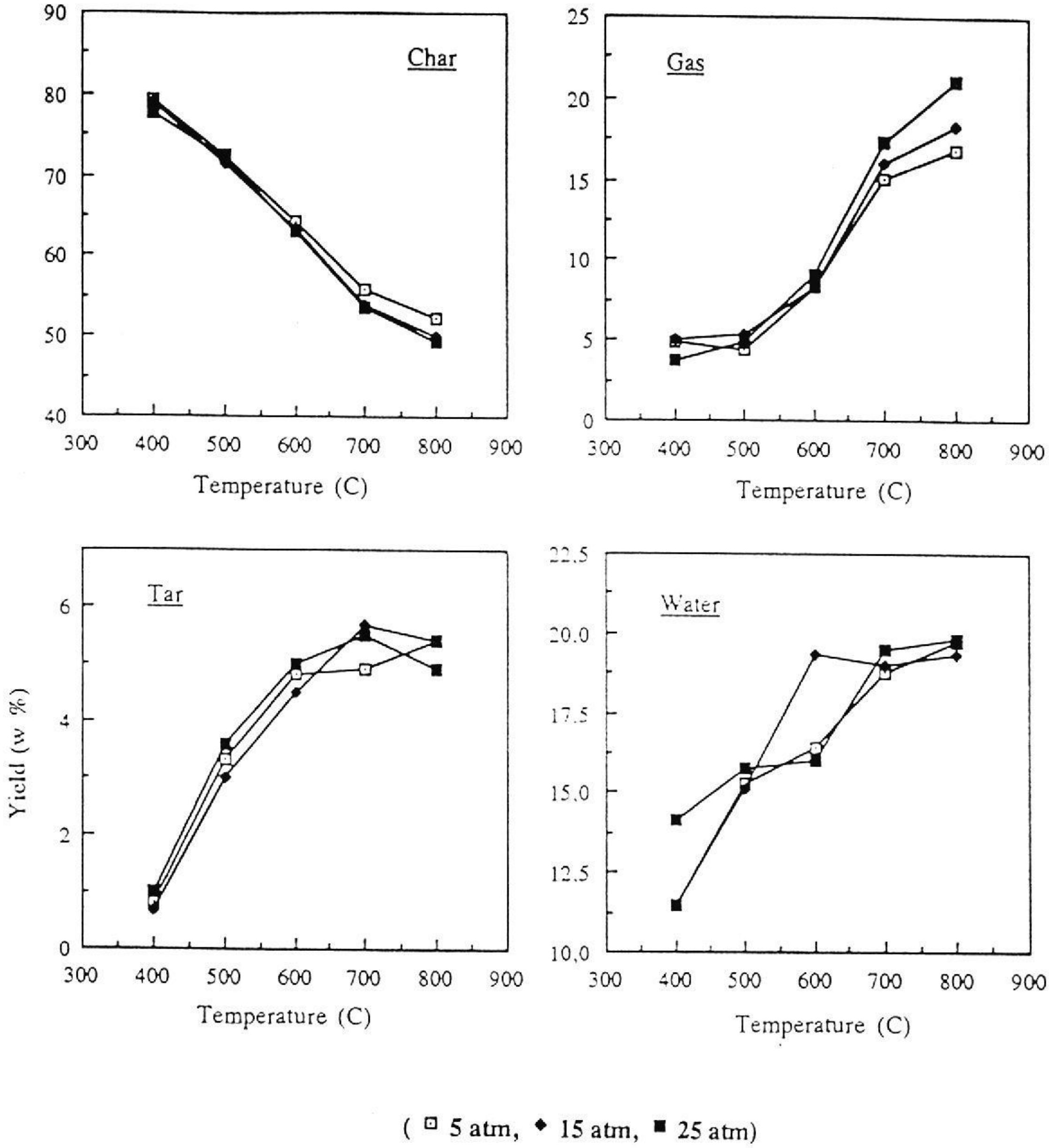


**Figure 8 . Effect of Pressure on Pyrolysis Product Distribution**

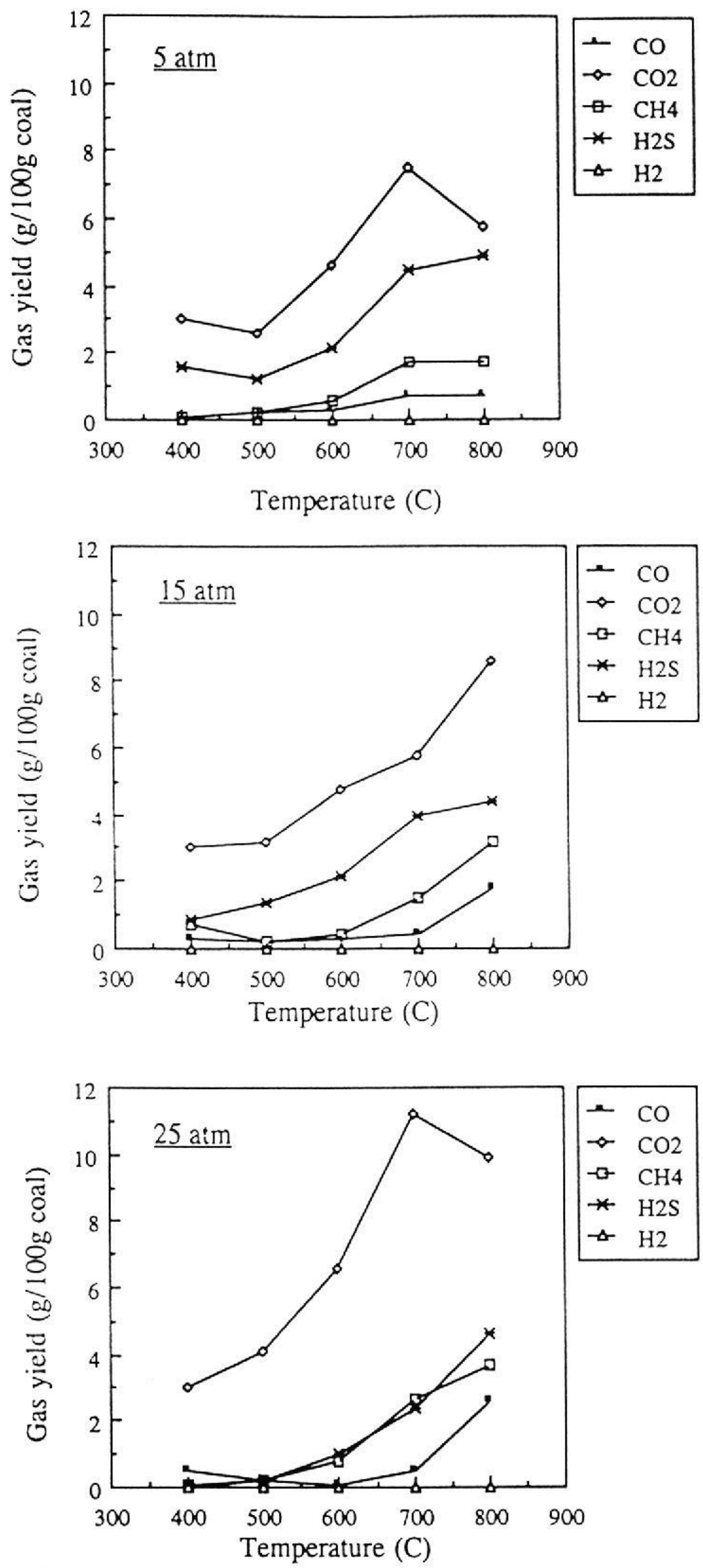


**Figure 9 . Composition of Pyrolysis Gas**

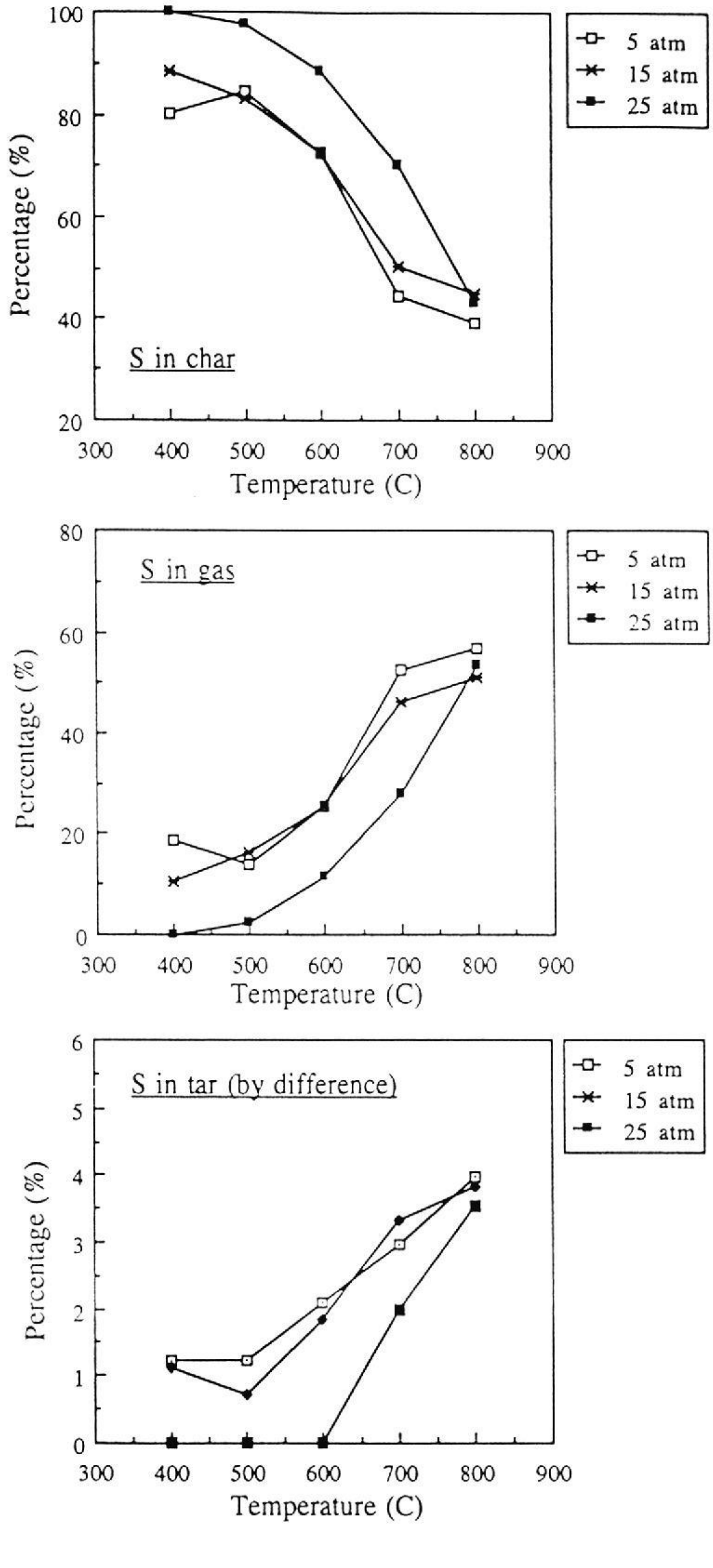


**Figure 10 . Sulphur Distribution in Pyrolysis Products**

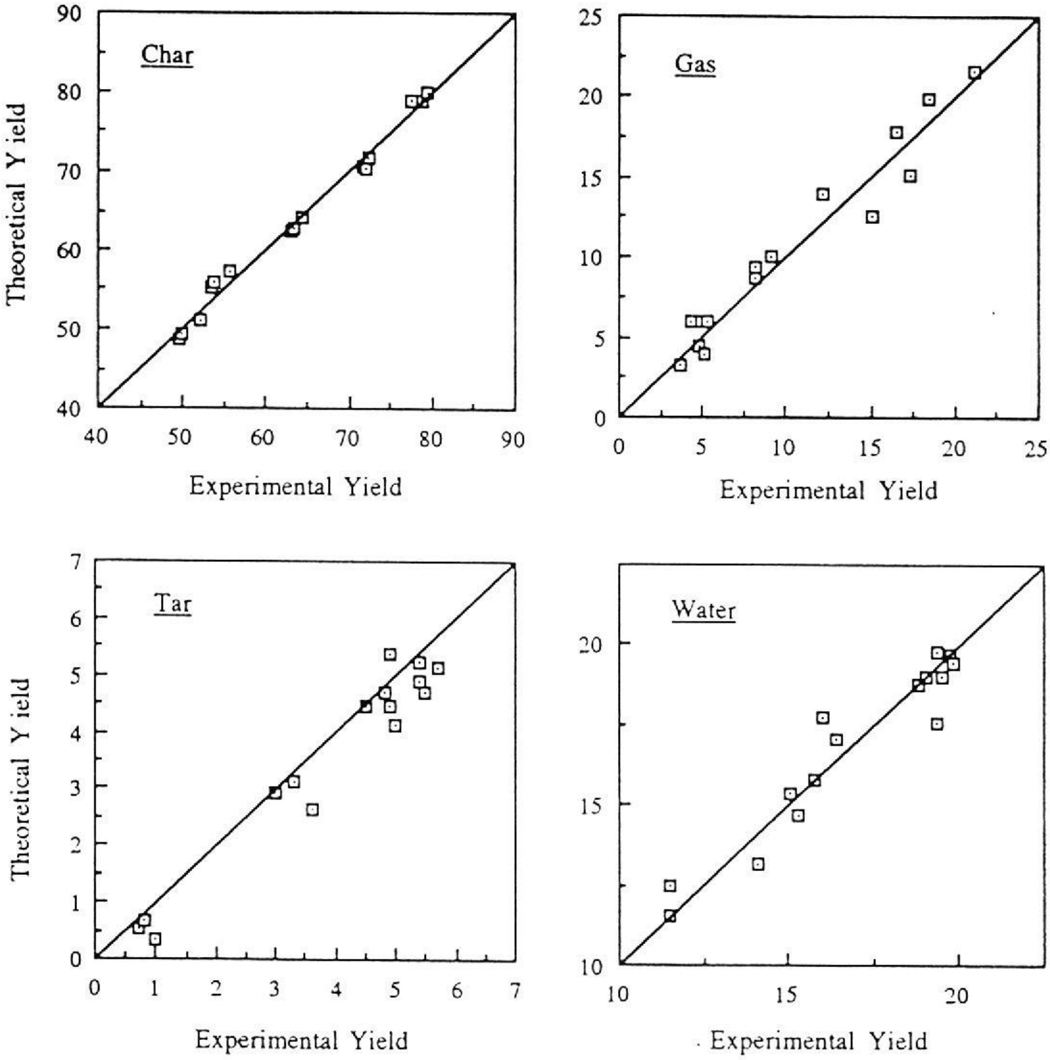


**Figure 11 . Comparison between Experimental Pyrolysis Product Data and Empirical Correlations**

| Measured Depth relative to GL (m) | Inclination (deg.) | Azimuth rel. to UTM North (deg.) | True Vertical Depth (m) | East - West displacement (m) | North - South displacement (m) |
|---|---|---|---|---|---|
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 15.80 | 0.30 | 180.72 | 15.80 | 0.00 | -0.04 |
| 35.80 | 0.30 | 180.87 | 35.80 | 0.00 | -0.15 |
| 55.80 | 0.30 | 179.18 | 55.80 | 0.00 | -0.25 |
| 75.90 | 0.25 | 199.73 | 75.90 | -0.02 | -0.34 |
| 95.90 | 0.33 | 197.01 | 95.90 | -0.05 | -0.44 |
| 115.80 | 0.26 | 224.37 | 115.80 | -0.10 | -0.53 |
| 135.90 | 0.17 | 204.82 | 135.90 | -0.14 | -0.59 |
| 155.80 | 0.17 | 237.83 | 155.80 | -0.18 | -0.63 |
| 176.00 | 0.13 | 254.79 | 176.00 | -0.23 | -0.65 |
| 195.90 | 0.01 | 64.98 | 195.90 | -0.25 | -0.66 |
| 216.00 | 0.07 | 47.74 | 216.00 | -0.23 | -0.65 |
| 236.00 | 0.16 | 341.22 | 236.00 | -0.23 | -0.61 |
| 256.00 | 0.11 | 107.78 | 256.00 | -0.23 | -0.59 |
| 276.00 | 0.13 | 35.77 | 276.00 | -0.19 | -0.58 |
| 296.00 | 0.09 | 341.75 | 296.00 | -0.19 | -0.55 |
| 315.90 | 0.12 | 25.95 | 315.90 | -0.18 | -0.51 |
| 336.00 | 0.18 | 352.20 | 336.00 | -0.18 | -0.46 |
| 356.00 | 0.47 | 359.85 | 356.00 | -0.18 | -0.35 |
| 376.00 | 0.55 | 356.67 | 376.00 | -0.19 | -0.17 |
| (KOP*) **393.00** | **1.22** | **226.17** | **392.99** | **-0.32** | **-0.22** |
| 395.70 | 1.94 | 214.18 | 395.69 | -0.37 | -0.27 |
| 405.80 | 6.27 | 212.83 | 405.76 | -0.76 | -0.88 |
| 415.80 | 10.20 | 211.83 | 415.65 | -1.53 | -2.09 |
| 425.80 | 13.39 | 207.20 | 425.44 | -2.52 | -3.87 |
| 430.80 | 15.17 | 205.52 | 430.28 | -3.07 | -4.98 |
| 435.80 | 17.10 | 204.22 | 435.08 | -3.65 | -6.24 |
| 440.80 | 18.82 | 203.64 | 439.84 | -4.28 | -7.65 |
| 445.90 | 20.40 | 202.90 | 444.64 | -4.95 | -9.22 |
| 450.80 | 21.80 | 201.50 | 449.21 | -5.62 | -10.85 |
| 455.80 | 23.45 | 199.69 | 453.83 | -6.29 | -12.65 |
| 460.80 | 25.04 | 197.87 | 458.39 | -6.95 | -14.60 |
| 465.80 | 26.81 | 196.12 | 462.88 | -7.59 | -16.69 |
| 470.80 | 28.91 | 194.31 | 467.30 | -8.20 | -18.94 |
| 475.80 | 31.04 | 192.32 | 471.63 | -8.78 | -21.37 |
| 480.80 | 33.13 | 190.35 | 475.87 | -9.30 | -23.98 |
| 485.80 | 34.88 | 188.25 | 480.01 | -9.75 | -26.73 |
| 490.80 | 36.48 | 186.07 | 484.08 | -10.11 | -29.63 |
| 495.80 | 38.13 | 184.25 | 488.05 | -10.38 | -32.65 |
| 500.90 | 39.47 | 183.13 | 492.03 | -10.59 | -35.83 |
| 505.90 | 40.20 | 182.50 | 495.87 | -10.75 | -39.03 |

**Table 1 . ET4 Trajectory based on Gyro Survey**

**(*) interpolated from adjacent survey points**

| Measured Depth relative to GL (m) | Inclination (deg.) | Azimuth rel. to UTM North (deg.) | True Vertical Depth (m) | East - West displacement (m) | North - South displacement (m) |
|---|---|---|---|---|---|
| 510.80 | 40.88 | 181.14 | 499.59 | -10.85 | -42.22 |
| 515.80 | 42.19 | 179.66 | 503.33 | -10.87 | -45.53 |
| 520.80 | 43.82 | 178.93 | 506.99 | -10.83 | -48.94 |
| 525.80 | 45.65 | 178.74 | 510.54 | -10.75 | -52.46 |
| 530.80 | 47.70 | 178.99 | 513.97 | -10.68 | -56.09 |
| 535.80 | 49.72 | 179.17 | 517.27 | -10.62 | -59.85 |
| 540.80 | 51.95 | 179.42 | 520.43 | -10.58 | -63.73 |
| 545.90 | 53.72 | 179.53 | 523.51 | -10.54 | -67.79 |
| 550.80 | 55.24 | 179.44 | 526.35 | -10.50 | -71.78 |
| **(9.5/8 *) 551.55** | **55.43** | **179.44** | **526.78** | **-10.50** | **-72.39** |
| 555.90 | 56.31 | 179.46 | 529.22 | -10.46 | -75.99 |
| 560.80 | 57.17 | 179.20 | 531.91 | -10.41 | -80.09 |
| 565.80 | 57.85 | 179.04 | 534.59 | -10.35 | -84.31 |
| 570.80 | 58.53 | 178.91 | 537.23 | -10.27 | -88.56 |
| 575.80 | 59.48 | 178.55 | 539.80 | -10.18 | -92.84 |
| 580.80 | 60.82 | 178.17 | 542.29 | -10.05 | -97.18 |
| 585.80 | 61.96 | 178.05 | 544.69 | -9.91 | -101-56 |
| 590.80 | 62.71 | 177.98 | 547.01 | -9.76 | -105.99 |
| 595.80 | 63.14 | 178.03 | 549.28 | -9.60 | -110.44 |
| 600.90 | 63.52 | 178.05 | 551.57 | -9.44 | -114.99 |
| 605.90 | 63.78 | 178.09 | 553.79 | -9.29 | -119.47 |
| 610.80 | 64.00 | 178.08 | 555.95 | -9.15 | -123.87 |
| 615.80 | 64.13 | 178.17 | 558.13 | -9.00 | -128.36 |
| 621.20 | 64.92 | 178.24 | 560.46 | -8.85 | -133.23 |
| **(6.5/8 *) 628.00** | **64.84** | **178.24** | **563.34** | **-8.66** | **-139.39** |
| (**) 632.81 | 64.40 | 178.30 | 565.41 | -8.53 | -143.73 |
| (**) 642.22 | 64.00 | 178.70 | 569.50 | -8.30 | -152.20 |
| (**) 651.54 | 63.10 | 179.30 | 573.65 | -8.16 | -160.54 |
| (**) 660.92 | 61.60 | 180.70 | 578.00 | -8.16 | -168.85 |
| (***) 675.50 | 59.30 | 182.80 | 585.19 | -8.54 | -181.52 |

Table 1(cont.) . ET4 Trajectory based on Gyro Survey

(*) interpolated from adjacent survey points
(**) based on MWD survey(open-hole section)
(***) extrapolated to bit

| Measured Depth relative to GL (m) | Inclination (deg.) | | | Azimuth rel. to UTM North (deg.) | | |
|---|---|---|---|---|---|---|
| | MWD | GYRO(*) | Δ | MWD | GYRO(*) | Δ |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 65.00 | 0.00 | 0.27 | 0.27 | 182.20 | 189.43 | 7.23 |
| 120.47 | 0.50 | 0.23 | -0.27 | 101.20 | 221.17 | 119.97 |
| 175.85 | 0.50 | 0.13 | -0.37 | 168.10 | 253.97 | 85.87 |
| 231.90 | 0.30 | 0.15 | -0.15 | 45.90 | 337.42 | -68.48 |
| 278.17 | 0.20 | 0.13 | -0.07 | 277.30 | 24.09 | 106.79 |
| 314.70 | 0.20 | 0.12 | -0.08 | 359.30 | 24.94 | 25.64 |
| 350.90 | 0.30 | 0.38 | 0.08 | 2.50 | 352.11 | -10.39 |
| 381.52 | 0.10 | 0.38 | 0.28 | 278.30 | 317.92 | 39.62 |
| 391.00 | 0.60 | 0.86 | 0.26 | 233.60 | 238.80 | 5.20 |
| 400.51 | 3.90 | 3.82 | -0.08 | 212.80 | 208.48 | -4.32 |
| 410.00 | 7.50 | 8.05 | **0.55** | 214.22 | 214.02 | -0.20 |
| 419.09 | 11.20 | 11.27 | 0.07 | 210.95 | 210.13 | -0.82 |
| 428.57 | 14.10 | 14.35 | 0.25 | 206.40 | 206.23 | -0.17 |
| 438.10 | 17.40 | 17.92 | **0.52** | 205.40 | 203.90 | **-1.50** |
| 446.84 | 20.70 | 20.67 | -0.03 | 204.10 | 202.68 | **-1.42** |
| 455.97 | 23.50 | 23.51 | 0.01 | 200.30 | 199.63 | -0.67 |
| 465.10 | 26.90 | 26.54 | -0.36 | 196.90 | 196.36 | -0.54 |
| 474.40 | 30.60 | 30.44 | -0.16 | 193.40 | 192.88 | -0.52 |
| 484.12 | 34.20 | 34.33 | 0.13 | 189.90 | 188.98 | -0.92 |
| 493.25 | 37.20 | 37.30 | 0.10 | 185.30 | 185.11 | -0.19 |
| 503.05 | 40.20 | 39.84 | -0.36 | 183.50 | 182.88 | -0.62 |
| 512.18 | 40.90 | 41.18 | 0.28 | 180.30 | 180.69 | 0.39 |
| 520.54 | 44.00 | 43.73 | -0.27 | 179.70 | 178.95 | -0.75 |
| 529.71 | 47.70 | 47.26 | -0.44 | 179.40 | 178.93 | -0.47 |
| 539.03 | 51.40 | 51.19 | -0.21 | 180.00 | 179.33 | -0.67 |
| 542.60 | 52.60 | 52.63 | 0.03 | 180.30 | 179.49 | -0.81 |
| 557.80 | 56.65 | 56.66 | 0.01 | 181.90 | 179.38 | **-2.52** |
| 567.50 | 58.05 | 58.07 | 0.03 | 180.70 | 179.01 | **-1.69** |
| 576.87 | 59.80 | 59.75 | -0.05 | 179.60 | 178.46 | **-1.14** |
| 586.44 | 61.10 | 62.08 | **0.98** | 178.50 | 178.04 | -0.46 |
| 595.57 | 63.10 | 63.12 | 0.02 | 178.10 | 178.03 | -0.07 |
| 604.96 | 63.60 | 63.73 | 0.13 | 178.50 | 178.09 | -0.41 |
| 614.19 | 64.30 | 64.00 | -0.30 | 178.50 | 178.14 | -0.36 |

**Table 2 . Comparison of ET4 MWD and Gyro Surveys**

**(*) interpolated from adjacent gyro survey points at corresponding MWD measured depths**

| | Case a)<br>Total Open Hole Length<br>(L = 124.1 m) | Case b)<br>Open Hole in Coal and Sand (L = 69. 1 m) | Case c)<br>Sand only<br>(L = 45.0 m) |
|---|---|---|---|
| Test n° 1 | 5.6 | 9.7 | 14.2 |
| Test n° 2 | 6.6 | 11.4 | 16.8 |

Table 3 . ET4 Fall-off Tests - Average Permeabilities(mD)

| Type of Product | Coefficient A | Coefficient B | Coefficient C | Coefficient D | Coefficient E | Coefficient F |
|---|---|---|---|---|---|---|
| Char | 152.0 | -0.0129 | -0.049 | $3.33\ 10^{-5}$ | $4.60\ 10^{-3}$ | $-1.95\ 10^{-4}$ |
| Pyrolysis | 28.5 | -0.0771 | -0.449 | $6.17\ 10^{-5}$ | $-7.00\ 10^{-3}$ | $6.15\ 10^{-4}$ |
| Water | -29.7 | 0.0845 | 0.289 | $-3.59\ 10^{-5}$ | $-1.50\ 10^{-3}$ | $-2.40\ 10^{-4}$ |
| Tar | -38.5 | 0.0874 | 0.038 | $-4.33\ 10^{-5}$ | $0.60\ 10^{-3}$ | $-0.55\ 10^{-4}$ |

Table 4 . Yield of Pyrolysis Products - Coefficients in the Empirical Correlation:
$\text{Yield} = A + B\,T + C\,P + D\,T^2 + E\,P^2 + F\,T\,P$ (*)

(*) Yield in wt % of initial coal, T in °C and P in bar