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

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TECHNICAL REPORT
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Summary

The main activities during the period of this report have been in the engineering design of process wells and surface plant, and the drilling of the third exploratory well.

The third exploratory well was drilled in March 1993 to provide information of great importance to subsequent drilling activities and process operation. The results of this well have been analysed and the **upper coal seam** has been selected for the underground gasification trial.

The planning of the deviated injection well was assisted by responses from five companies specialised in deviated drilling who were approached early in January 1993 with requests to provide technical advice and a detailed programme of drilling operations. On the basis of a drilling plan formulated taking their advice into consideration, orders for all the deviated injection well materials/equipment were issued in Spring 1993 with the latest delivery expected end August 1993. The drilling operations of the deviated injection well are foreseen for the months September-October 1993.

Selection of the engineering contractor to conduct the basic engineering of surface plant was made in February 1993, the company John Brown Sener S.A. being selected. The works began in April 1993 and will be completed by August 1993.

The two related works in the supporting programme, at the Universities of "Louvain-la Neuve(Belgium)" and "Liege(Belgium)", were completed and final reports were received.

1. INTRODUCTION

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

A third exploratory well was drilled in order to answer the remaining questions regarding the continuity of the two coal seams. The results of this well were considered sufficient to make the final selection of coal seam, the upper coal seam being considered to be the best seam in which to conduct the underground gasification trial.

The detailed engineering and procurement of equipment for the deviated well were made in parallel to the exploration activities in order that the drilling operations for this well could begin in September-October 1993.

Six quotations were received in response to the invitation to tender for the basic engineering of the surface plant. These were analysed in February 1993 and a contract for the work was placed with John Brown Sener S.A. in April 1993. The work is in progress and will be completed by August 1993. The results of the basic engineering will be used to define the requirements for the detailed engineering design and the procurement/construction phase of the surface plant following the deviated well drilling.

2. EXPLORATORY WELL(ET3)

2.1 STRATEGY AND DESIGN

The well was drilled to answer several questions that remained after drilling the second exploratory well ET2, answers that were important for subsequent drilling activities(mainly the deviated in-seam well) and process operation. These concerned dip regularity, the thickness and mean thickness of the seams, possible faults between ET2 and T7, paleochannel erosion over the upper seam, and the possibility of splitting of the lower seam.

The well ET3 was located to realise a triangular correlation of the three exploratory wells ET1-ET2-ET3 over the future reaction zone and to get more information in the vicinity of the future recovery well. The location of ET3 is 83.5 metres to the South of the first exploratory well ET1, 45.4 metres to the Southwest of the second exploratory well ET2, and 116.5 metres to the Northwest of the exploratory well T7 drilled by ENDESA in 1974(see Figure 1).

The UTM co-ordinates of the well ET3 are:

X: 718549.7 m
Y: 4532577.6 m
Z: 664.0 m

UGE decided that the well would be drilled on weekdays only basis, i.e. no weekend working, in order to minimise its cost, the hole quality being relatively unimportant(no setting/cementing of casing). The only operations foreseen in the well were the coring of the coal seams and their roofs and floors, and a logging programme including LDL, CNL, GR, ML and SHDT.

2.2 OPERATIONS

2.2.1 Contractors

The following contractors were selected for the operations and services involved in the realisation of the third exploratory well ET3:

– Civil works Concrete platform for the derrick Cellar and guide tube Channels to drain mud	ARIDOS GRACIA
– Casing Supply of 9 5/8" casing	IBERICA DE SONDEOS
– Drilling Drilling 12 1/4" Casing and cementing 9 5/8" Drilling 8 1/2" Coring 4" Preparation for logging Cementing the well	IBERICA DE SONDEOS
– Logging Dipmeter/geometric log(SHDT, GR) Geophysical combined log(LDL, GR, ML, NL) – *Cancelled*	SCHLUMBERGER

2.2.2 Site/platform preparation

The previously prepared main access to the field trial site was used without requirement for additional maintenance. Only minor works were necessary to prepare the site for the drilling activities for ET3. The works consisted of:
- construction of 18m x 3.5m concrete platform with a cellar and guide tube
- construction of a channel to drain the mud from rig platform to mud pit

2.2.3 Rig operations

The MAYHEW 2500 rig that drilled the two previous wells was selected and arrived on site on 23 February 1993. The rig, pumps, tanks, shale shaker, desander, etc. were installed in the following days, and initial 12 1/4" drilling/ 9 5/8" casing phases were completed by 4 March.

From 27 February to 31 March 1993, the following operations were done:

– Drilling	12 1/4"	0 - 68 m	27 Feb.- 2 Mar.
– Casing/cementing	9 5/8"	0 - 67 m	2 Mar.– 4Mar.
– Drilling	8 1/2"	68 -574 m	4 Mar.– 24 Mar.
– Coring	4"	574 610.7 m	24 Mar.– 26 Mar.

– Reaming	8 1/2"	574 -610.7 m	26 Mar.
– Coring	4"	610.7-623.2m	27 Mar.
– Reaming	8 1/2"	610.7-623.2 m	29 Mar.
– Drilling	8 1/2"	623.2-624.2 m	29 Mar.
– Open-hole logging		to total depth	29 Mar.– 30 Mar.
– Well cementing		19.5m to total depth	30 Mar.– 31 Mar.

A summary of the operating time distribution is given in Table I.

The drilling contractor was left to control mud quality on the basis of the advice and information provided by the mud company during drilling of the exploratory well ET2. Different muds were used for the two drilling phases:

– 12 1/4" phase: basic bentonitic mud

– 8 1/2" phase: mud with Bentonite, CMC(high and low viscosity), caustic soda and Spersene, whose initial properties were:

density(mud weight)	1.07 kg/l
funnel viscosity	36 – 38 s
filtrate(water loss)	7.5 – 9 cm^3 / 30 min
pH	8.5-9

No important changes occurred during drilling except for an increase of density to 1.12 – 1.14 kg/l in the late stages of the 8 1/2" drilling phase, which was attributed to the addition of clays from the formation to the mud. Control of this effect was attempted by frequent dumping and changing mud. The sand content was maintained between 0.4 - 0.5 %.

Deviation of the well from vertical was measured during drilling by TOTCO inclination surveys, giving values between 0.25 – 1°, the last check point at 623 m being 0.75° from vertical. A final inclination/Dipmeter log(SHDT) by SCHLUMBERGER gave greater inclinations than these values, in the range 0.75 – 1.8° from vertical, with deviation azimuth of 350 – 360° (to the North-Northwest).

Three significant events/features were apparent during the drilling of the exploratory well ET3:

- During tripping, overpull was required in some sections of the well, on several occasions.
- An influx of water into the hole was detected during a "running into hole" on the 21st day of progress(29 March), one day before reaching total depth, during coring of the Jurassic limestone. It was not possible to estimate the quantity of water entered.
- Hole quality(diameter by calliper) was very bad in the lowest section of the

Tertiary, reaching 12" in many zones. As a result of this and because of a bad cable tension reading during the SHDT log, it was decided not to run the LDL-CNL(Litho-Density Log – Compensated Neutron Log) tool because of the risk of sticking in the caved zones. The information obtained by SHDT log(with GR log) was considered sufficient to correlate and recognise the coal seams and surrounding strata.

2.3 INTERPRETATION

2.3.1 Lithology[from drilling cuttings, coring and logging)

The lithology of the exploratory well ET3(see Figures 2a and 2b) can be categorised as follows:

- Tertiary(0 – 441 m). This zone is composed of clay, conglomerate, marls and sands. The sand zones present the higher porosity. Along this section, the calliper shows a diameter much higher than the drilling diameter(8.5"). The mean diameter is 10" with some diameters up to 12" in the zone 350 to 410 m. The sand zones are the only exception with a calliper between 8.5" and 9". The eccentricity of the hole was also observed with difference in diameter reaching 2". The clay zones indicate gamma emission between 60 – 90 API with a peak of 109 API at 350 m. The sand zones have a range of emission of 20 – 40 API.
- Cretaceous-Cenomanian(441 – 472 m). This zone is composed of red/brown and varicoloured marls(red, grey, yellow...) with some red and white clays and a 2.5 – 3 metre bed of calcarenite. The rate of penetration was very low. The upper part of this zone is recognised by a sharp decrease of resistivity combined with an increase of gamma emission(max. 93 API at 446 m). No cavities exist in this zone and the calliper indicates diameter similar to the drilling diameter (< 9").
- Cretaceous-Albian/Aptian(472 – 608.3 m). The upper part of this zone called Utrillas Formation is mainly composed of clay and sand. The clayey zones are the most important and they separate the sand layers in independent aquifers. The two coal seams separated by a layer of impermeable limestone are situated at the lower section of this zone (the "Val de la Piedra" Formation). The total zone can be divided into the following sub-zones for more detailed analysis:

  -Sub-zone A(472 – 488 m). In its upper section, this zone is composed of two important clay layers separated by a sand layer. Its lower section is a transition zone to the sand sub-zone B with intermediate natural gamma emission between those of the upper clay zones and those of the floor sand zones. In addition, the two clay layers present the particularity of a lower calliper(+/- 8") than the drilling diameter(8.5"), probably due to the

swelling behaviour of the clay.
-Sub-zone B(488 – 492 m). This zone is composed of the cleanest sands within the Cretaceous zone with high permeability and low gamma ray emission(11 to 33 API).
-Sub-zone C(492 – 514 m). In its upper and intermediate section, this zone is composed of clayey sand/sandy clay with a medium gamma ray emission. The presence of up to 0.23" mud cake at different points is also an indication of high to medium permeability. The lower part is composed of clay with a maximum gamma ray emission of 395 API at 510 m.

-Sub-zone D(514 – 549 m). This zone is mainly a sandy zone with the upper section up to 526 m slightly argillaceous and the lower section composed of fine sand/silt. Nearly all of the section is characterised by an important mud cake(between 0.25" and 0.5"), an indication of a good permeability.
Sub-zone E(549 – 574 m). This zone mainly composed of clay is characterised by its high gamma ray emission(between 125 and 140 API). A gamma marker of 318 API appears at 566.5 m . The calliper indicates also important changes in diameters: important cavities with diameters up to 10" are contiguous with zones of low diameters(7.3"). The swelling effect of the clay was not observed in the wells ET1 and ET2, and could be explained by the montmorillonitic composition of the clay present in this section in the well ET3.
Sub-zone F(574 – 587.6 m). This zone constitutes the roof of the upper coal seam and is composed mainly of clayey sand. The upper part is more clayey with gamma ray emission between 68 and 105 API. The lower part indicates low values of gamma ray emission and shows coal inclusions. With regard to the calliper, it is noted as in the wells ET1 and ET2 a decrease in diameter(+/- 7.6") at the near roof of the coal seam.
Sub-zone G(587.6 – 590.3 m). This zone corresponds to the upper coal seam of the "Val de la Piedra" Formation. The coal seam thickness of 2.7 m, 1.2 m less with respect to ET1 and 0.3 m higher with respect to ET2 indicates still a strong paleochannel erosion by the roof sand. The coal is well consolidated with no indication of faults, and is of good quality(low ash content). Table II summarises the logging data of the upper coal seam, and its adjacent roof and floor. The coal seam exhibits still a high level of gamma ray emission in its lower part.
Sub-zone H(590.3 – 590.7 m). This zone constitutes the immediate floor of the upper coal seam and is composed of carbonaceous clay with lower gamma ray emission than the bottom of the coal seam.
Sub-zone I(590.7 - 602.5 m). This zone is composed of grey limestone slightly marly which changes progressively to carbonaceous/ calcareous mudstone in the last metres. Carbonaceous inclusions increasing in density going deeper can be observed all along the zone. To the depth of approx. 600 m, the values of gamma ray emission are very low(6 to 10

API) and the values of the resistivity very high. The very smooth curves of the gamma and resistivity logs recorded in this zone indicate also the very good homogeneity and the very low permeability of the limestone. The calcareous/carbonaceous mudstone of the coal seam roof shows an increase of the gamma ray emission with a peak value of 42 API at 601 m. The calliper increases also to 9.5" in this section.
Sub-zone J(602.5 - 607.7 m). This zone corresponds to the lower coal seam of the "Val de la Piedra" Formation. The quality of the coal seam has deteriorated in this well to highly carbonaceous mudstone. The percentage of ash reaches 40 – 45 %. The results of the logging are presented in the Table III.
Sub-zone K(607.7 – 608.3 m). This zone constitutes the bottom of the Cretaceous-Albian/Aptian Formation and is composed of carbonaceous clay with root inclusions. The gamma ray emission of this zone is lower than the gamma ray emission of the carbonaceous mudstone.

- Jurassic(608.3 – 624.2 m). The Jurassic is composed of re-crystallised limestone that presents an important network of fractures filled with black clay. The density of fractures diminishes with depth but the fractures are still present at Total Depth(TD). These fractures are reflected in the resistivity log by abrupt jumps in the recording. Another particularity of this zone is the abnormally high level of gamma ray emission that is the consequence of the important quantity of clay filling the fractures.

2.3.2 Dipmeter

As for the previous wells, the SHDT log was processed in SCHLUMBERGER's computer centre with a basic correlation programme "Mean Square Dip"(MSD), which finds the "best fit" satisfying all possible cross-correlation. These results were analysed to interpret the structural dip/azimuth and detect possible structural and/or stratigraphical anomalies in the formations crossed: Tertiary, Cretaceous and Jurassic.

Tertiarv

In general, the dip angles measured by the Dipmeter are almost constant with the exception of some sections that exhibit high dispersion and consequently a very low reliability. The structural dips at some points in the Tertiary Formation are;

Depth(m)	Dip(°)	Azimuth(°)
85	30.4	N168W
171	29.7	N170W
222	30.2	N161W

271	30.7	N177W

Due to their small amplitude, small fractures inside the Tertiary Formation are not detected with certainty by the Dipmeter. On the other hand, a study of the gamma ray, Dipmeter and resistivity logs in combination has enabled the recognition of different sequences of sedimentation in the Tertiary. For example, between 96 and 122 m, five superposed channelling actions have been recognised which probably correspond to different river levels during different periods. This type of sedimentation is very frequent throughout the whole of the Tertiary column. Similar phenomena are also recognised between 207 and 222 m, 285 and 315 m, and 355 and 373 m.

Cretaceous

The interpretation of the structural dip of the Cretaceous Formation is less clear due to the importance of cross-bedded strata.

The statistical study of the MSD results is presented in Table IV from which the significant dispersion of the results can be seen. The Cenomanian has a structural dip of approx. 30°. Below the Cenomanian, abrupt changes in sedimentation, the results of paleochannel and lagoon sedimentation, have given still higher dispersion in dip angle. Some strata dip to the SW and SE and have no relation to the structural dip. Some strata dip at higher or lower angles than the structural dip(+/- 30 – 35°). The structural dips at points in the Cretaceous Formation are:

	Depth(m)	Dip(°)	Azimuth(°)
Cenomanian			
	443	28.1	N177W
	445	29.4	N182W
Albian/Aptian			
	476	30.3	N175W
	541	35.3	N179W
	570	32. 0	N183W

Jurassic

The statistical study of the Jurassic Formation indicates a mean structural dip of 14.6° with very high dispersion. This value is much smaller than the structural dip registered in the previous exploratory wells for the Jurassic Formation. Due to the high dispersion of the results, probably the consequence of important fracturation of this zone, this value should not be considered as representative of the real structural dip of this Formation.

3. SITE CHARACTERISATION

3.1 ET1 - ET2 - ET3 CORRELATION(see Figure 3)

A comparison of the coal seam section of the three exploratory wells ET1-ET2-ET3 can be summarised as follows:

Clayey sand roof

Measured thickness in well = 14.0 m(ET1), 12.6 m(ET2), 13.6 m(ET3). Erosion by the sand in all the wells. Greatest effect in well ET2. Presence of coal fragments inside the immediate roof of the coal seam.

Upper coal seam

Measured thickness in well = 3.9 m(ET1), 2.4 m(ET2), 2.7 m(ET3). Good quality coal with low ash content(< 16 %) in all the wells. Well-consolidated coal with no presence of faults. Good continuity of the coal seam between the three wells(based on seam floor / top limestone correlation).

Intermediate limestone(including carb. clay-bottom upper coal seam and carb. mudstone/clay-top lower coal/ *seam)*

Measured thickness in well = 8.3 m(ET1), 11.8 m(ET2), 12.2 m(ET3). Similar carbonaceous clay marker(+/- 20 - 60 cm) at the floor of the upper coal seam in all the wells. Similar compact limestone with "characeas" and carbonaceous inclusions in all the wells. The grey limestone at the top of this zone changes progressively to a carbonaceous/calcareous mudstone at the roof of the lower coal seam. The thickness of the intermediate limestone increases slightly going to the South, i.e. ET1⇒ET2⇒ET3.

Lower coal seam

Measured thickness in well = 3.6 m(ET1), 4.5 m(ET2), 5.2 m(ET3). Good quality coal with low ash content(< 14 %) in the wells ET1 and ET2. The quality of the coal seam has deteriorated in well ET3 to a highly carbonaceous mudstone(ash content between 36 – 42 %). Good continuity of the coal seam at a dip angle slightly greater than that of the upper seam.

Clay(Albian)/limestone(Jurassic) floor

The coal seam in ET1 lies immediately on the Jurassic limestone(faults?). A carbonaceous clay layer(Bottom Albian) exists between the coal seam and the limestone in the wells ET2 and ET3. The Jurassic limestone is strongly fractured in all the wells, the fractures filled with black/grey clay.

In order to realise a triangular correlation of the three exploratory wells, SCHLUMBERGER was requested to compute the trajectories of the three exploratory wells from the Dipmeter logs. On the basis of these trajectories and the interpretation of the lithology of the three exploratory wells, the following co-ordinates were defined and used for the geometrical calculation of the plane corresponding to the top of the intermediate limestone(floor of the upper coal seam), recognised as the best geological marker;

Top of Limestone(floor upper coal seam) – UTM Co-ordinates

	ET1(m)	ET2(m)	ET3(m)
X	718558.3	718585.0	718547.3
Y	4532666.5	4532610.0	4532588.3
Z	120.6	88.0	73.5

The plane defined by these co-ordinates has a dip angle of 30° 51' and a dip azimuth of 184° 00' relative to UTM North – figures that are within the ranges expected from knowledge of the general disposition of the deposit and which support the prognosis that the upper seam should be unfaulted within the area bounded by the wells. In addition, this dip angle is in good agreement with the mean dip angles of 31.56°(ET1), 33.23°(ET2) and 32.65°(ET3) calculated from the SHDT Dipmeter over the Albian section.

3.2 COAL ANALYSIS

A comprehensive analysis of the cores taken from the three exploratory wells has been performed by INSTITUTO DE CARBOQUIMICA(ZARAGOZA). Average values of proximate, ultimate and sulphur compound analysis are tabulated in Tables V – X. The average values have been calculated by weighting measurements according to the number of metres represented.

The results show that the coal is of excellent quality and that the rank according to the ASTM standard is class C sub-bituminous. The quantity of water present is very high which ranks the coal close to a lignite.

It should also be noted from the elemental analysis that the coal has a relatively low hydrogen content and a very high organic sulphur content. These characteristics of the Teruel coal are probably unique in the world, being outside the normal range for this type of coal.

The pyritic sulphur content recorded in the well ET3 is significantly higher than in the wells ET1 and ET2, demonstrating the non-uniform distribution of pure pyrite blocks within the coal seam.

3.3 SEAM SELECTION

Results from the third exploratory well ET3 substantially clarify the many uncertainties that remained following the drilling of ET2:

– Good continuity of both coal seams between the three exploratory wells, an indication of the absence of geological faulting over the gasification zone.

-The paleochannel erosive action over the upper coal seam has decreased in ET3, resulting in an increase in coal thickness of 0.3 metres with respect to ET2 and a mean true thickness of the upper coal seam of 2.6 metres.

– The dip angle of the upper coal seam is confirmed at $\approx 31^{o}$ to the horizontal, this dip being that of the horizon defined by the top of the intermediate limestone in wells ET1, ET2 and ET3.

– The lower coal seam in ET3 has deteriorated into a very carbonaceous mudstone-siltstone, whilst retaining some calorific value.

The geometrical and coal analysis information suggests that the upper coal seam offers the best conditions for in-seam drilling and gasification. The upper seam has therefore been selected as the target for the deviated injection well ET4; the in-seam section of the well will be at the target dip and azimuth defined by the three exploratory wells and at a target horizon 50 cm above the roof of the intermediate limestone, i.e. at the interface of the thin carbonaceous clay layer above the intermediate limestone and the floor of the upper seam.

4. ENGINEERING

4.1 WELLS

The UCG project at the "El Tremedal" field site comprises two main areas of activity. The first area involves the drilling and completion of the process wells: the second area involves the design and provision of the facilities required to construct a flow circuit through the coal seam via the drilled wells and to operate the underground gasifier.

In order to prepare the basic engineering of these both activities in parallel, documents describing in detail (i) the functions of the process wells and their interconnections with the surface plant, and (ii) the process phases were issued early January. These documents are presented as Appendices A and B.

The process wells to be drilled are the deviated injection well[IW1(ET4)], the recovery well[RW(ET5)] and the transverse injection well[IW2(ET6)]. In addition to these three process wells, the exploratory wells ET1 and ET2 will be adapted by work-over for use as monitoring wells[MW1(ET1) and MW2(ET2)].

The drilling and construction of the deviated in-seam injection well is a key point of the project and this well will be drilled before other wells and before the procurement /construction of the surface plant.

4.1.1 Deviated Injection Well[IW1(ET4)] - Drilling Programme

The trajectory, and the drilling and casing programmes for this well have been finalised. On the basis of advice from directional drilling companies, the well will be drilled in standard oil industry sizes to benefit from their familiarity with the performance and behaviour of conventional DHM/BHA's, and to minimise the difficulties in procurement of casing and liner components.

The build angle will be approx. 12.5° / 100 ft (= 140 m radius). Potential difficulties in running 9 5/8" casing at this build angle through the Albian and hole stability in the coal are covered by contingency planning and procurement in the drilling and casing programmes.
Land for the trial was acquired on the basis that the radius of the deviated inseam well would be 100 metres(17.4° / 100 ft build rate). Consequently, the rental of a small additional piece of land has been negotiated to provide additional area for drill rig location and access.

The foreseen drilling operation programme can be summarised as follows:

- The 17 1/2" hole will be drilled and the 13 3/8" surface casing will be run and cemented at or near vertical at approx. 60m depth(below water table). Below this casing the well will be drilled in 8 1/2" and kicked off at approx. 405 m to achieve 59° inclination in the lower part of the upper coal seam, i.e. the first target point in the coal seam. The 8 1/2" hole will be opened to 12 1/4" prior to setting and cementing the 9 5/8" casing at approx. 560 m MD.
- Below the 9 5/8" casing shoe, 8 1l2" hole will be directionally drilled to = 50 cm from the floor of the coal seam(at inclination approx. 59°) over a length in-seam of 100 metres. Four additional targets are to be achieved, at 10, 40, 70 and 100 m along the in-seam section(the future CRIP).
- a 7" / 6 5/8" tubing/liner with instrumentation(encapsulated control line clamped on the outer side) will be run from surface to TD.
- In the event of inability to run the 9 5/8" casing to the planned casing point, this casing will be set at the greatest depth possible and an additional 7" casing will be set and cemented at the planned casing point in the lower part of the coal seam. In this case, 6" hole will be drilled as close as possible to the floor over the in-seam section and a 4 1l2" tubing/liner with instrumentation will then be run to TD.
- In the event of inability to run the 7" / 6 5/8" tubing/liner with instrumentation to TD in the in-seam coal section in the programme plan, this tubing will be run to the greatest depth possible and an additional 4 1/2" liner without instrumentation will be run to TD following hole cleaning.

4.1.2 Deviated Injection Well[IW1(ET4)] - Tenders/Procurement

Orders for casing, tubing, instrumentation and wellhead have been placed, with the latest quoted delivery date end-August 1993.

Invitations to Tender for services have been requested from the following companies with closing date for receipt of tenders 12 July 1993:

Drilling Services(Rig)	British Drilling and Freezing Cofor Foramines Sonpetrol
Directional Drilling MWD and Surveying	Anadrill Schlumberger Baker Hughes Inteq Geoservices Directional Scientific Drilling Controls Sperry Sun Halliburton Drilling Services
Drilling Fluids(Mud)	International Drilling Fluids M-I Drilling Fluids Milpark Drilling Fluids
Bits	Reed Tool Hughes Christensen Dresser Smith International

Halliburton and Dowell-Schlumberger have been approached to advise on the cementing programme for the well and to provide quotations.

4.1.3 Other wells

Work on product well design has begun. For this well, the optimum design of casing/tubing configuration and insulation will be established with the benefit of the results of the analyses performed by the Universities of "Louvain-la Neuve(Belgium)" and "Liege(Belgium)" in the supporting programme, and potential suppliers will then be approached to determine materials availability and manufacturing capabilities.

4.2 SURFACE PLANT

A contract for Phase 1 of the Surface Plant Engineering(Basic Design) was placed with John Brown Sener S.A. in April 1993. The work comprises a review/comment of the initial design produced by UGE from which the basic engineering of the surface plant and equipment will be conducted in sufficient detail to establish an initial cost estimate. The basic engineering package will include all the standard sheets/drawings required to begin the detailed engineering(mass balance, PID's, process data sheets, site plot plan and preliminary arrangement, equipment specification list, instrumentation list, hazardous areas and fire water system).

The work should be completed by August 1993.

4.3 SUPPORTING PROGRAMME

Two projects in the supporting programme, at the Universities of "Louvain-la Neuve(Belgium)" and "Liege(Belgium)", were completed and final reports were received.

Universite Catholique de Louvain(Prof. J. Patigny)

The modelling/simulation of the heat losses and pressure changes for three recovery well-configurations(insulated tubing, insulated casing, no insulation) were conducted. The conclusions of the study can be summarised as follows:

The insulated tubing solution is recommended, a maximum of 0.03 W/mK being suggested for the heat conductivity of the insulated tubing. A certain safety margin should be applied to this limit in respect to the tubing characteristics provided by the supplier.

Water condensation cannot be avoided in small tubing provided for the exhaust of gas/liquid products during temporary, transitional phases. For the production tubing, no absolute guarantee is given regarding to the total absence of condensation, especially during the first hours/days of the gasification phases. It is proposed that an alloy able to resist wet acid corrosion for approx. 100 hours be used for the production tubing and for the total period of transitional phases for the small tubing.

It is feasible to control the temperature of the main part of the production tubing to below 350 °C by water cooling.

Two additional risk areas remain to be investigated:

- Temperature in excess of 350 °C at the bottom of the production tubing.
- Risk of flooding inside the production tubing. If the water entrainment conditions are fulfilled, only the upper part of the production tubing will be exposed to wet acid corrosion.

Universite de Liege(Prof. J.-P. Pirard)

Flow and pressure distribution calculation

Calculation of flows and pressure distributions by Boundary Element Method(BEM) Flow Model for the final linking phase and the reverse combustion/pyrolysis phase was realised assuming two-dimensional condition, constant coal permeability and simple geometry. The influence of the distance between wells, well diameter, flow condition, coal permeability and hydrostatic pressure were analysed. This study has provided a useful indication for the final design of the bottom hole completion of the injection and recovery wells, and for the specification of the process parameters(pressure and flow ranges) during the final linking and the reverse combustion/pyrolysis phases.

Gasification product composition calculation. Influence of the sulphur.

The calculation of the gasification product composition by Chemical Equilibrium Based Model was realised. A bibliographic/theoretical analysis of the reactions involving the different forms of sulphur in the UCG process was also realised prior to their introduction in the existing Model. The reactions involving sulphur were introduced in the Model in a simple way: the organic sulphur reacts completely to form H2S, the reactions with the sulphates are negligible and the pyrite is decomposed in a hydrogen atmosphere to FeS and H2S. This simple model should be improved/completed by experimental work on coal pyrolysis to determine the partition of the sulphur compounds between the different gasification products(gas, liquid/tar, ash). This model has given a useful indication of the gasification product composition for the design of the equipment for product gas handling and disposal.

5. PROJECT DIRECTION

5.1 ADMINISTRATION

Three additional staff(Instrumentation/Process Engineering/Administration) has been recruited during this period, bringing the team strength to 10. The team is nevertheless below target number and additional staff will be engaged during the second half of the year. The main areas in which effort and expertise are now required are:

- Process engineering (Planning operations in process phases)
– Elect./data processing (Collection, processing and presentation of data during process phases)
– Field engineer (Co-ordination of field activities, contractors, safety and environment)

Contact has been made with architect and construction services to realise the conversion of the second floor of the office building in early September. This increase in office space will allow the recruitment of the additional staff above mentioned.

5.2 PROBLEMS/DIFFICULTIES

No significant technical difficulty was encountered during the period of this report.

An issue that could affect future progress is the long delivery time (up to four months) for the procurement of some items of equipment for the deviated injection well. The time required could have an important impact on the overall duration of the project.

5.3 CHANGES IN TECHNICAL STRATEGY

The exploratory well ET3 was drilled to answer several questions remaining after the drilling of the second exploratory well ET2 that were important issues for subsequent activities. One of its main objectives was to provide additional information and confidence in the continuity of the two coal seams. The results of the well are considered sufficient to select the upper seam, this offering the best conditions and disposition for subsequent drilling and gasification.

5.4 FUTURE WORK

The deviated injection well, one of the key points of the project, will be drilled in September-October 1993. All the equipment for this well is ordered for which the latest delivery time quoted is end-August 1993. Contracts for the drilling, directional drilling and fluid services for the well will be signed early in September 1993.

Phase 1 of the Surface Plant Engineering (Basic Design) will be completed in August 1993. Phase 2 of the Surface Plant Engineering (Detailed Design) will be initiated following the drilling and completion of the deviated injection well.

Work on the pyrolysis and reactivity behaviour of the El Tremedal black lignite will begin at the INSTITUTO DE CARBOQUIMICA as part of the supporting programme.

Suppliers of special alloy and insulated tubing for the production well will be contacted for final technical advice before tendering and procurement.

5.5 CONFERENCES, PUBLICATIONS AND REPORTS

- "Informe Geologico y de Perforacion del Sondeo Tremedal 3(67/IN/94/S) Internal report prepared by C. BARAT, A. OBIS.

- "Modelling heat losses and pressure changes in a recovery well" (UGE ref. 21)
  Report prepared by University of Louvain-la-Neuve, Louvain-la-Neuve(Belgium).

- "Study of the Flows in a Virgin Coal Seam by the Boundary Element Method"(UGE ref. 25)
  Report prepared by University of Liege, Liege(Belgium).

- "The role of Sulfur in the Reactions of Underground Coal Gasification" (UGE ref. 26)
  Report prepared by University of Liege, Liege(Belgium).

- "Informe de Analysis Inmediato y Elemental sobre Muestras de Carbon" (11873 a 11886, 11949 a 11951)
  Report prepared by Instituto de Carboquimica, Zaragoza(Spain)

Day	Drilling	Stop / Mainte-nance	Rig Manoeuvre + Totco	Mud Prep./ Circul.	Casing Setting	Cementing / Waiting	Coring	Reaming	Logging	Others
1	8.00		3.00							1.00
3	18.00		2.00							4.00
4	9.75		4.00	1.00				5.75		3.50
5					3.00	21.00				
6	11.75		1.50	0.50		5.00				5.25
7.	16.25		5.25	1.00						1.50
10	18.50		3.00	1.50						1.00
11	18.25		5.25	0.50						
12	19.00		4.25	0.75						
13	22.50		1.25	0.25						
14	15.25		7.00	0.75						1.00
17	15.50	0.75	5.00					1.75		1.00
18	21.00		2.50	0.50						
19	18.50		5.50							
20	15.50		4.75	2.00						1.75
25	15.25		6.50	0.25						2.00
26	1.75		14.25	1.00			4.00			3.00
27			12.00	0.50			11.50			
28			12.50	0.75			2.50	8.25		
29			12.50				10.00			1.50
32	0.75		7.75	2.25				8.00	4.50	0.75
33			2.00			15.00			2.00	5.00
34			1.00			23.00				
Total	245.50	0.75	122.75	13.00	3.00	64.00	28.00	23.75	6.50	32.75

Table I. Exploratory Well ET3 Operating Time Distribution(Hour.Min)

Depth(m)	Gamma Ray	Lithology	Core % Recovery
586.50	60	Argillaceous	100
587.00	51	Sand	"
587.58	25	Coal	100
587.75	22	"	"
588.00	231	"	"
588.25	34	"	"
588.50	57	"	"
588.75	95	"	"
589.00	139	Coal	100
589.25	162	"	"
589.50	150	"	"
589.75	104	"	"
590.00	52	"	"
590.25	20	"	"
590.33	18	Coal	100
590.50	11	Carbonaceous	100
591.00	12	Clay	"

Table II . Upper Coal Seam Log Data at ET3(API Units)

Depth(m)	Gamma Ray	Lithology	Core % Recovery
601.50 602.00	33 30	Carbonaceous Mudstone	100 "
602. 54	50	Carbonaceous	100
602.75	52	Mudstone	"
603.00	50	"	"
603.25	49	"	"
603.50	51	"	"
603.75	53	"	"
604.00	55	"	"
604.25	50	"	"
604. 50	49	"	"
604. 75	49	"	"
605.00	50	Carbonaceous	100
605.25	52	Mudstone	"
605.50	53	"	"
605.75	55	"	"
606.00	57	"	"
606.25	58	"	"
606.50	61	"	"
606.75	69	"	"
607. 00	90	"	"
607.25	100	"	"
607. 50	82	Carbonaceous	"
607.65	63	Mudstone	100
608.00 608. 50	37 51	Carbonaceous Clay	100 "

Table III. Lower Coal Seam Log Data at ET3(API Units)

Lithology		No of Data	Mean Value	Standard Deviation	Minimum	Maximun
CENOMANIAN	Clays/Marls	63	30.4°	8.6°	2.7°	48.2°
ALBIAN	Multicolored Clay + Grey / Black Sand	232	32.8°	11.2°	6.7°	63.8°
	Upper Coal Seam	6	36.3°	4.5°	30.6°	43.1°
	Intermediate Limestone	24	32.5°	7.6°	4.5°	44.8°
	Lower Coal Seam	11	27.0°	8.6°	13.0°	37.1°

Table IV . Statistical Study of the Structural Dip of the Cretaceous Formation (ET3)

	Total Moisture (wt%)			Ash (wt%)			Fixed Carbon (wt%)			Volatile Matter (wt%)			High Heating Value (kcal/kg)		
	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3
Coal Seam	28.1	19.7	18.9	14.7	12.9	15.2	32.5	38.8	36.8	24.7	28.6	29.1	3785	4705	4496
	22.2			14.3			36.0			27.5			4329		
Carbonaceous Clay	-	18.3	-	-	47.4	57.2	-	11.3	11.4	-	23.0	16.3	-	1850	1447
	16.7			52.3			11.4			19.6			1649		

Table V . Proximate Analysis of the Upper Coal Seam Section (as received basis)

	Total Moisture (wt%)			Ash (wt%)			Fixed Carbon (wt%)			Volatile Matter (wt%)			High Heating Value (kcal/kg)		
	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3
Carbonaceous Mudstone	17.7	9.5	15.5	40.3	41.4	38.4	15.9	25.9	23.8	26.1	23.2	22.3	2452	3125	3010
	14.2			40.0			21.9			23.9			2862		
Coal Seam	26.1	21.4	-	13.3	13.4	-	33.6	37.7	-	27.0	27.5	-	4221	4520	-
	23.8			13.3			35.7			27.2			4371		
Carbonaceous Clay	-	6.7	8.6	-	75.9	76.2	-	4.6	3.3	-	12.8	11.9	-	645	547
	7.7			76.0			4.0			12.3			596		

Table VI . Proximate Analysis of the Lower Coal Seam Section (as received basis)

	C (wt%)			H (wt%)			N (wt%)			S (wt%)			O (wt%)			HHV (kcal/kg)		
	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3
Coal Seam	70.4	72.4	71.5	4.6	3.7	3.3	0.5	0.6	0.7	6.6	6.5	6.0	17.9	16.8	18.5	6578	6979	6832
	71.4			3.9			0.6			6.4			17.7			6796(6780*)		
Carbona. Clay	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5383	5232
	-			-			-			-			-			5308		

Table VII . Elemental Content of the Upper Coal Seam Section (moisture ash free basis)

* HHV_T (Kcal/kg) = 84 C(wt%)+ 277.65H(wt%)+ 15N (wt%)+ 25 S(wt%)-26.5 O(wt%) (ref. W Boie Formula)

	C (wt%)			H (wt%)			N (wt%)			S (wt%)			O (wt%)			HHV (kcal/kg)		
	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3
Carbona. Mudstone	65.3	67.5	68.6	4.6	2.9	3.4	0.6	0.7	0.9	-	4.9	4.4	-	24.0	22.7	5765	6370	6542
	67.1			3.6			0.7			4.7			23.9			6226(6131*)		
Coal Seam	74.0	71.2	-	4.7	3.3	-	0.5	0.5	-	5.2	5.6	-	15.6	19.4	-	6958	6911	-
	72.6			4.0			0.5			5.4			17.5			6935(6888*)		
Carbona. Clay	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3718	3590
	-			-			-			-			-			3654		

Table VIII . Elemental Content of the Lower Coal Seam Section (moisture ash free basis)

* HHV_T (Kcal/kg) = 84 C(wt%)+ 277.65H(wt%)+ 15N (wt%)+ 25 S(wt%)-26.5 O(wt%) (ref. W Boie Formula)

	Total Sulphur (wt %)			^{S}Pyritic (wt%)			^{S}Sulphate (wt%)			^{S}Organic (wt%)		
	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3
Coal Seam	7.4	6.9	8.4	2.6	2.4	4.4	0.9	0.1	0.1	3.9	4.4	3.9
	7.6			3.1			0.4			4.1		
Carbonaceous Clay	-	6.8	5.8	-	-	-	-	-	-	-	-	-
	6.3			-			-			-		

Table IX . Sulphur Distribution of the Upper Coal Seam Section (as received basis)

	Total Sulphur (wt %)			^{S}Pyritic (wt%)			^{S}Sulphate (wt%)			^{S}Organic (wt%)		
	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3	ET1	ET2	ET3
Carbonaceous Mudstone	4.1	4.3	4.3	-	1.8	2.2	-	0.1	0.1	-	2.4	2.0
	4.3			2.0			0.1			2.2		
Coal Seam	4.5	5.8	-	1.7	2.1	-	0.4	0.2	-	2.4	3.5	-
	5.2			1.9			0.3			3.0		
Carbonaceous Clay	-	7.0	3.3	-	6.4	3.0	-	0.3	0.1	-	0.3	0.2
	5.2			4.7			0.2			0.3		

Table X . Sulphur Distribution of the Lower Coal Seam Section (as received basis)

APPENDIX A

LAYOUT AND DESCRIPTION OF THE WELLS (EL TREMEDAL UCG FIELD TRIAL}

The wells directly involved in the Underground Coal Gasification(UCG) process are of three types:

Injection Well(IW)
Recovery Well(RW)
Monitoring Well(MW)

The figure A-1 gives a representation of the well layout.

A) Injection Wells

One of the objectives of the trial is to compare two different gasification processes. For this reason, two injection wells will be drilled: a deviated in-seam injection well to test the channel gasification combined with Controlled Retraction Injection Point(CRIP) manoeuvres, and a second vertical injection well offset of the axis of the previous gasification zone to test the reverse combustion/pyrolysis and filtration gasification process.

a) The deviated in-seam injection well[IW1(ET4)]

This well will be drilled following the dip(approx. 31°) of the coal seam, as close

as possible to the floor of the coal seam(approx. thickness 2.5 – 3.4 metres). The in-seam distance will be approx. 100 metres. This well will serve principally

as the injection well during the channel gasification phases with CRIP manoeuvres(Phases 5 and 6). It will be used also as injection well during the preparatory phases(Phases 1 to 4) and the shutdown phases(Phases 10 and 11). During the reverse combustion/pyrolysis and filtration gasification phases(phases 7 to 9), the well will be put in stand-by conditions.

The well will be composed of the following items(see Figure A-2):

- Casing 9 518" cemented up to the end of the curved part.
- Tubing 7" / liner 6 5/8" installed from wellhead to the end of the in-seam section. One fibre optic loop and two double thermocouples(four measurement points) will be clamped outside the tubing/liner.
- Coiled tubing 1 3/4" extended with 1.66" tubing and equipped at the end

with a burner/injection head. Two control lines(macaroni 6 – 8 mm) and two thermocouples will also be connected inside/outside the coiled tubing/tubing string.

This well configuration will imply the following connections for the surface plant:

- Fluid connections
  Annulus casing/tubing
  Annulus tubing/coiled tubing
  Coiled tubing
  First macaroni(ignition fluid plus combustible)
  Second macaroni(supporter of combustion)
- Downhole instrument connections
  One fibre optic loop(CRIP and cavity growth control)
  Four temperature measurements along the liner(CRIP and cavity growth control)
  Two temperature measurements at the tip of the burner/injection head(ignition control)

b) The transverse vertical injection well[IW2(ET6)]

This well will be drilled into the floor of the coal seam at a lateral distance of about 35 metres from the axis of the in-seam section of the deviated injection well. This second injection well will be used first to initiate a reverse pyrolysis/combustion process(Phases 7 and 8) from the cavity produced during the channel gasification phase. Secondly, the well will serve as injection well for the filtration gasification process(Phase 9). During the preparatory phases(Phases 1 to 4) and the channel gasification/CRIP phases(Phases 5 and 6), the well will remain in stand-by conditions. After the filtration gasification phase, the well will also be used as injection well for the shutdown phases(Phases 10 and 11).

The well will be composed of the following items(see Figure A-3):

- Casing 7" cemented from the roof of the coal seam to the surface and fitted in front of the coal seam with a 7" perforated liner.
- Tubing 1.66" installed from the wellhead to the coal seam level and equipped at the end with a burner/injection head. Two control lines(macaroni 6 - 8 mm) and two thermocouples will also be connected outside the tubing string.

This well configuration will imply the following connections for the surface plant:

- Fluid connections
  -Annulus casing/tubing
  -Tubing

-First macaroni(ignition fluid plus combustible)
-Second macaroni(supporter of combustion)

- Downhole instrument connections
  Two temperature measurements at the tip of the burner/injection head(ignition control)

B) Recovery Well[RW(ET5)]

This well will be drilled near to vertical to intersect as closely as possible the end of the in-seam section of the deviated injection well(IW1). The recovery well will be used for the removal of products(water, nitrogen, reverse combustion products, gasification products, shutdown products) during all the process phases(Phases 1 to 11). The only exception is the ignition phase(Sub-phase a) of the linking phase(Phase 4) where the recovery well will be used as an injection/ignition well.

The well will be composed of the following items(see Figure A-4):

- Casing 10 3/4" cemented from the roof of the coal seam to the surface and fitted in front of the coal seam with a 10 3/4" perforated liner.
- Insulated tubing 7" – 5" fitted at the end with 20 - 30 metres of 5" refractory steel tubing and installed from the wellhead to the level of the coal seam. One fibre optic loop and three double thermocouples(six measurement points) will be clamped outside the insulated tubing/tubing string.
- Tubing 1.66" installed from the wellhead to some metres below the coal seam floor(water exhaust by air lift) and equipped some metres above the coal seam with a burner. Two control lines(macaroni 6 – 8 mm) and two thermocouples will also be connected outside the tubing string.
- Water pipes installed and connected outside the insulated tubing/tubing string.

This well configuration will imply the following connections for the surface plant:

- Fluid connections

-Annulus casing/insulated tubing
-Annulus insulated tubing/small tubing Small tubing
-First macaroni(ignition fluid plus combustible)
-Second macaroni(supporter of combustion)
-Water pipes

- Downhole instrument connections

-One fibre optic loop(well temperature profile)
-Six temperature measurements along the insulated tubing/tubing string(temperature and water cooling control at well bottom)
-Two temperature measurements at the burner level(ignition control)

C) Monitoring Wells

Two previously drilled exploratory wells will be used for monitoring the UCG process: the first exploratory well(ET1) situated near to the landing point of the deviated injection well[IW1(ET4)] at the floor of the coal seam, and the second exploratory well(ET2) situated approx. 30 metres transverse to the first CRIP manoeuvre injection point.

a) The vertical monitoring well[MW1(ET1)]

The existing cased(7" casing) exploratory well(ET1) will be equipped with a 1.66" tubing string and two double thermocouples(four measurement points) clamped outside. The tubing and thermocouples will be cemented in place(see Figure A-5). The thermocouples will measure the temperature at the level of the coal seam.

This well configuration will imply the following connections for the surface plant:

- Downhole instrument connections
  Four temperature measurements at the coal level(cavity growth control)

b) The transverse deviated monitoring well[MW2(ET2)]

From the existing cased(7" casing) exploratory well(ET2), a short radius(approx. 12 – 14 metres) deviated section will be drilled inside the coal seam. The in-seam distance will be approx. 10 – 15 metres. The well will be equipped with a 1 3/4" coiled tubing up to the end of the in-seam section. The coiled tubing will contain internally one fibre optic loop and two double thermocouples(four measurement points). This equipment will be cemented in place(see Figure A-6).

This well configuration will imply the following connections for the surface plant:

- Downhole instrument connections
  One fibre optic loop(cavity growth control)
  Four temperature measurements distributed along the in-seam section(cavity growth control)

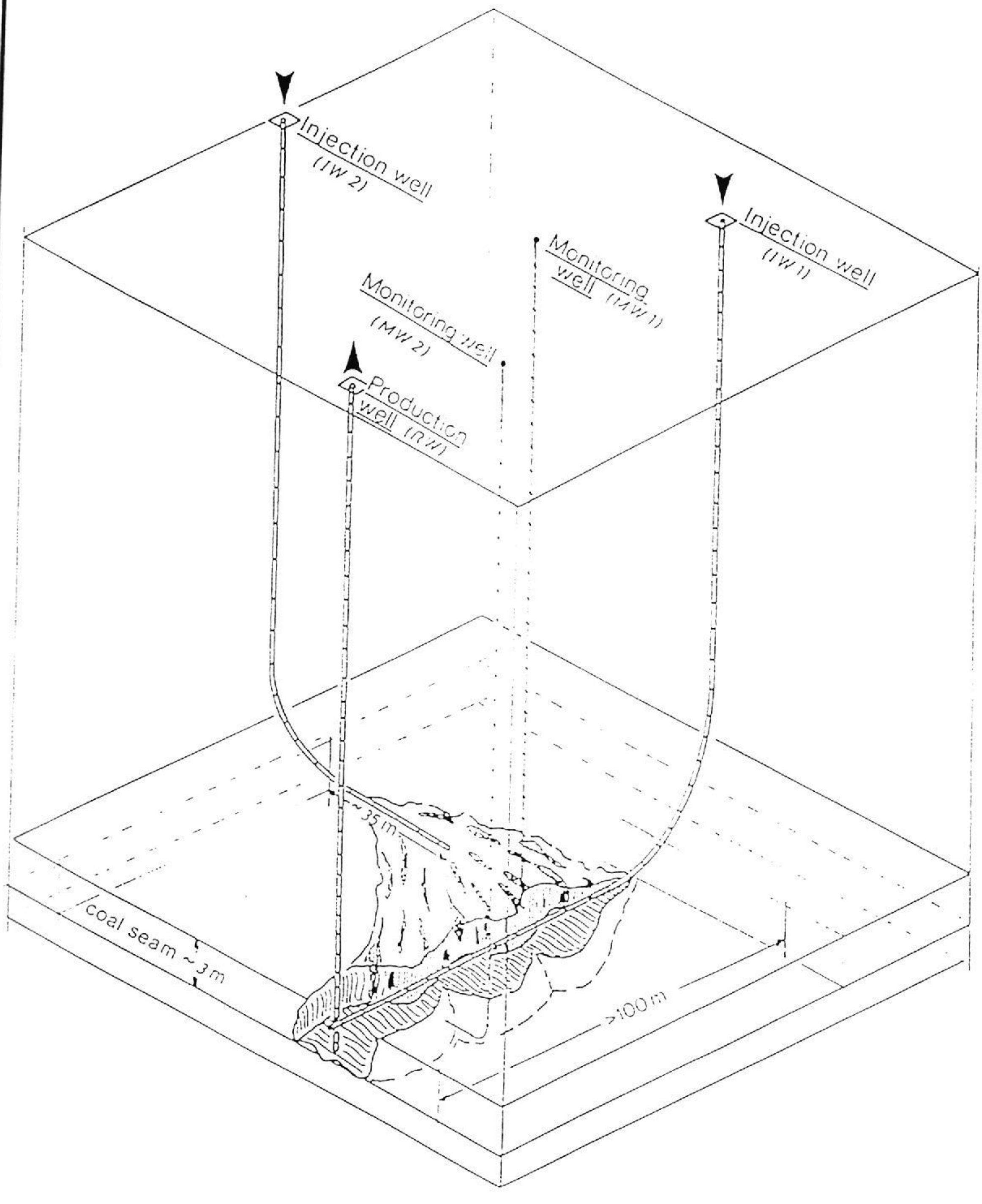

Figure A-1 . Well Layout

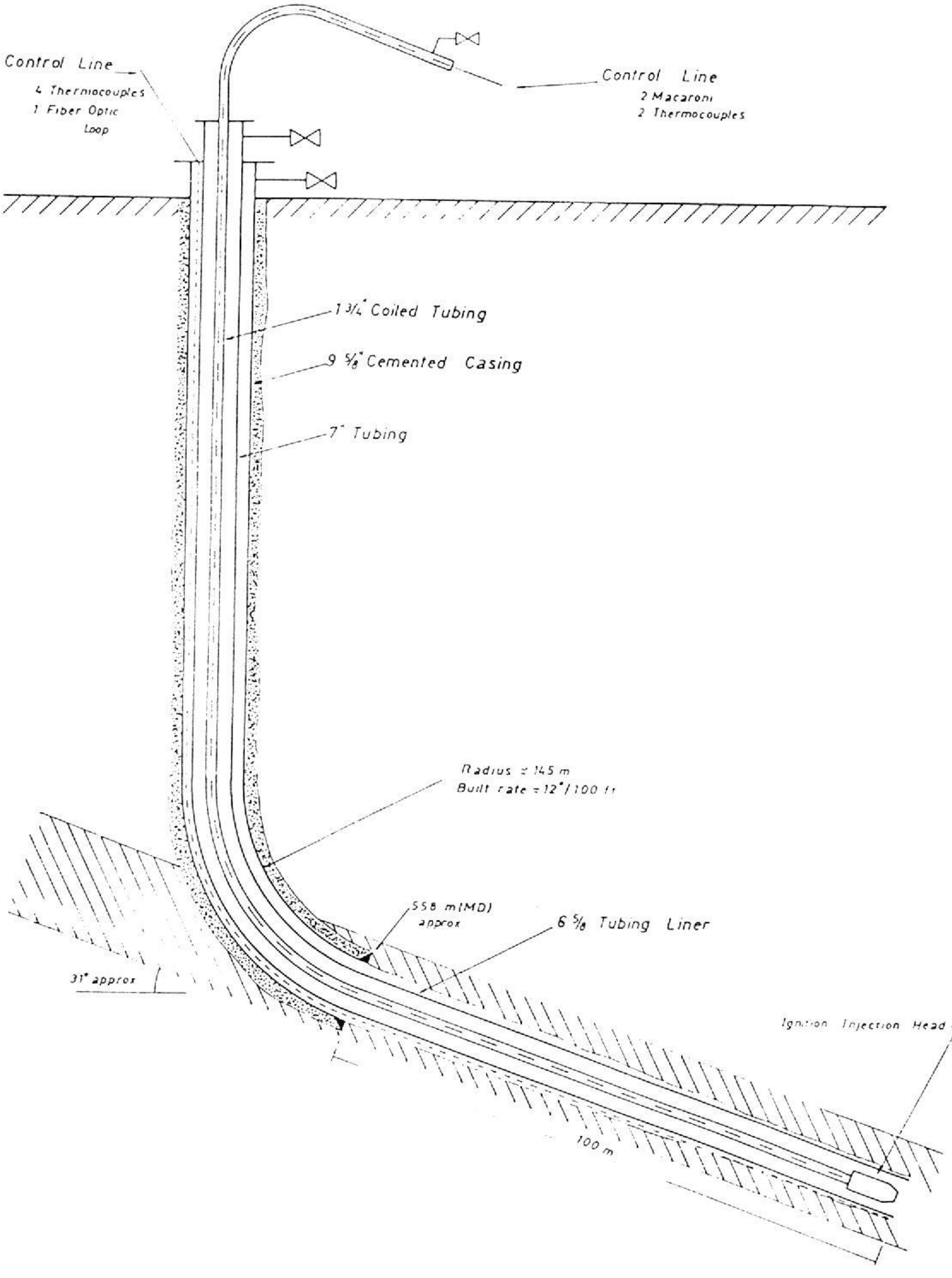

Figure A-2 . Deviated Injection Well Completion(IW1)

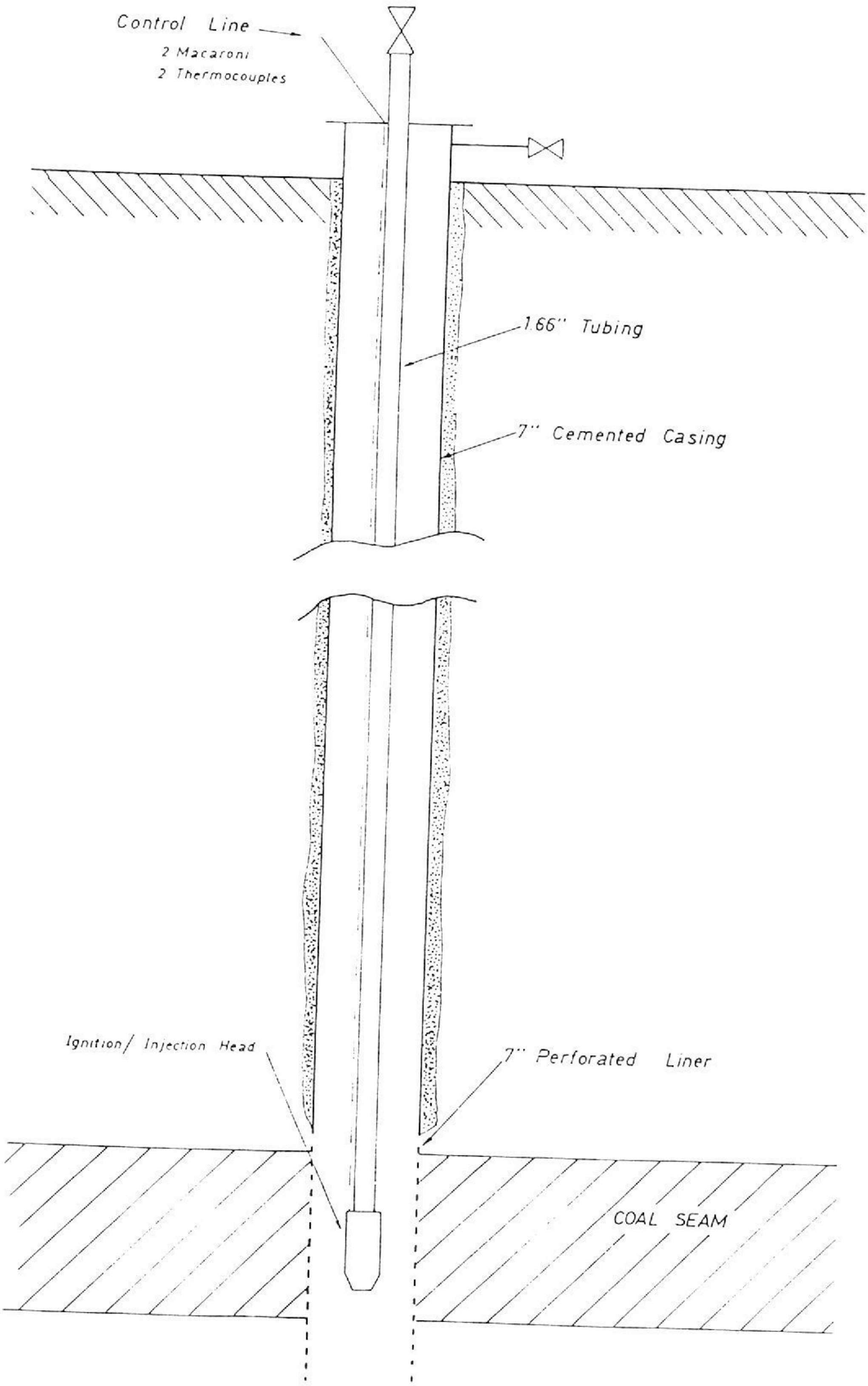

Figure A-3 . Vertical Injection Well Completion(IW2)

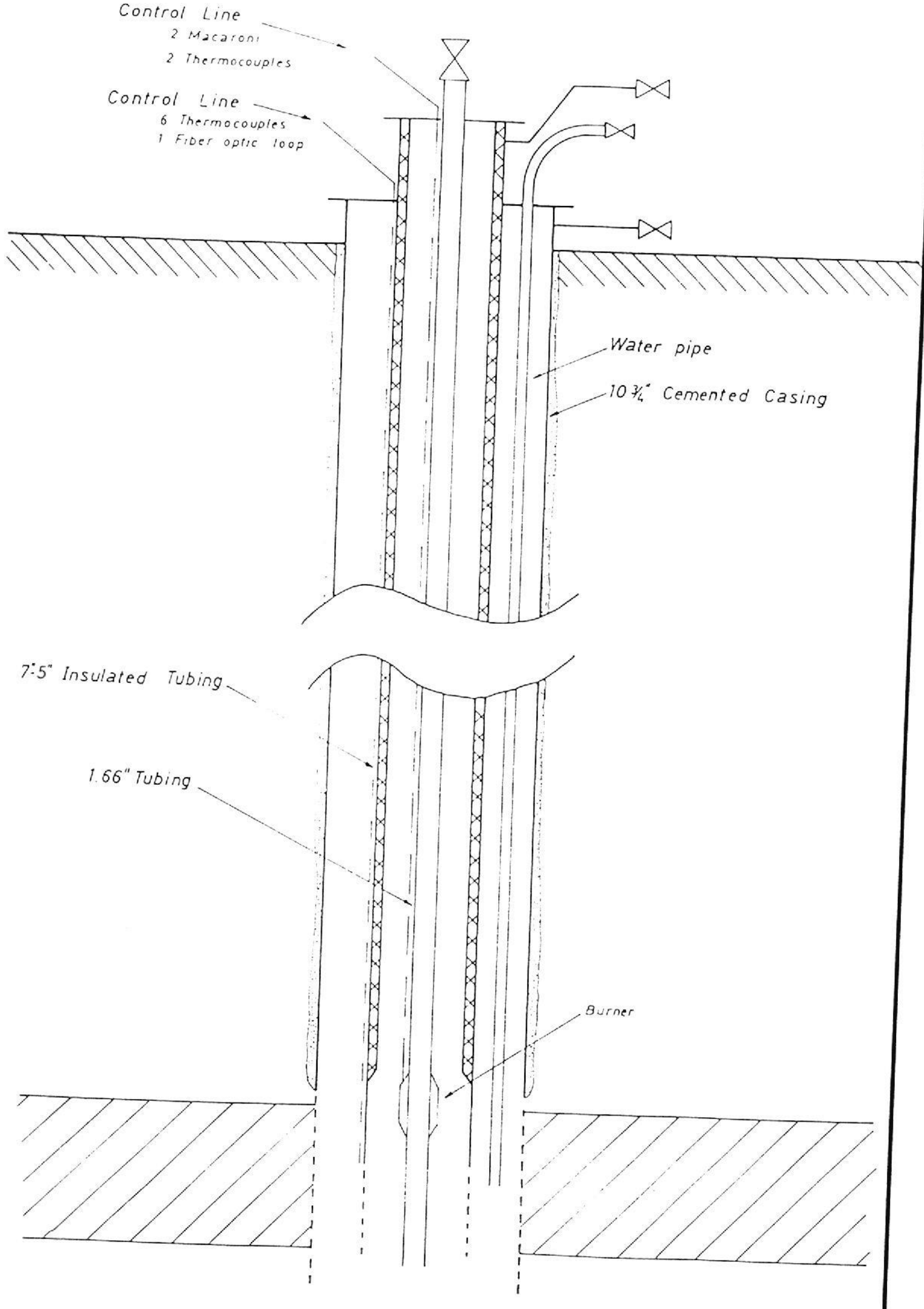

Figure A-4 . Recovery Well Completion(RW)

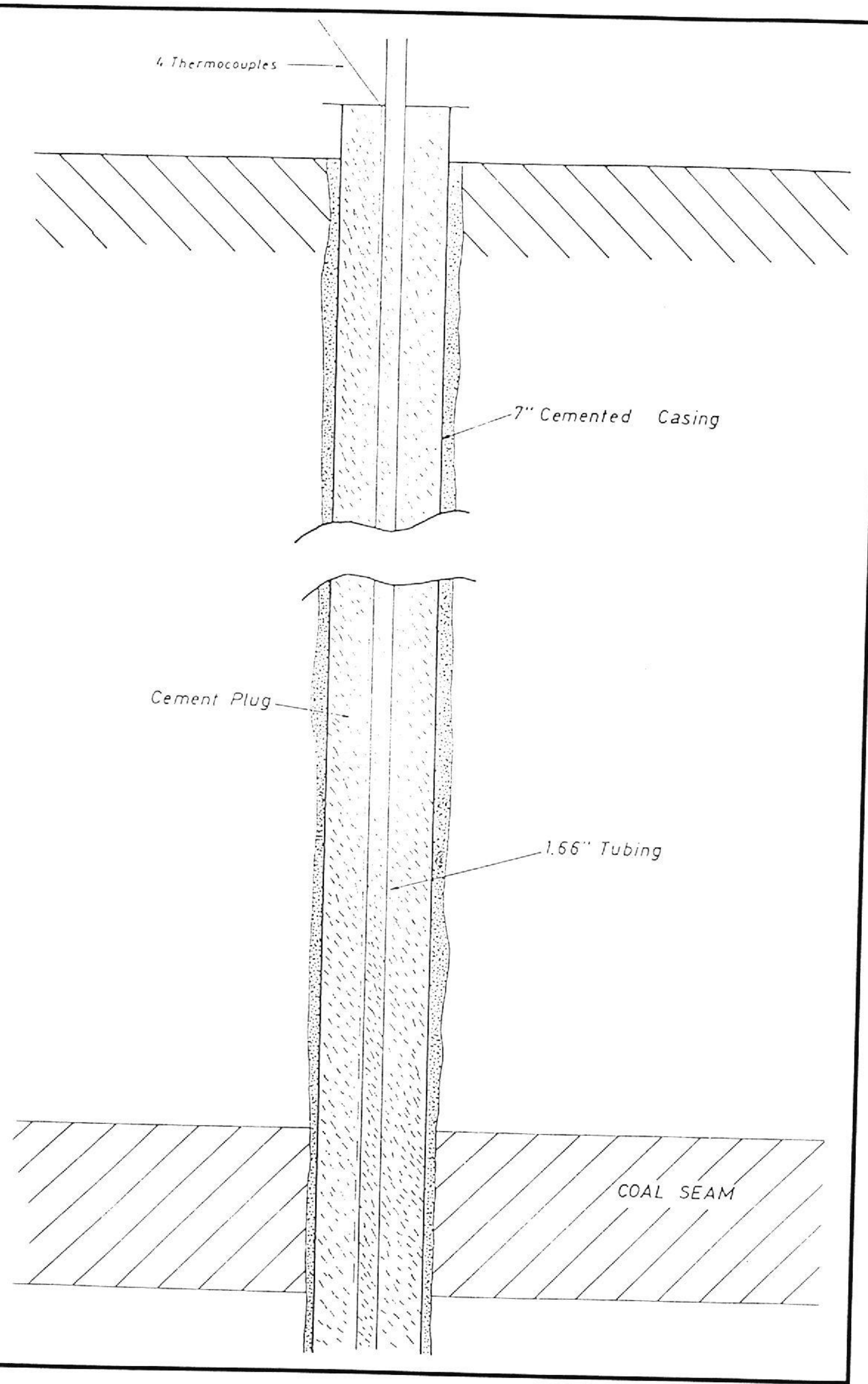

Figure A-5 . Vertical Monitoring Well Completion(MW1)

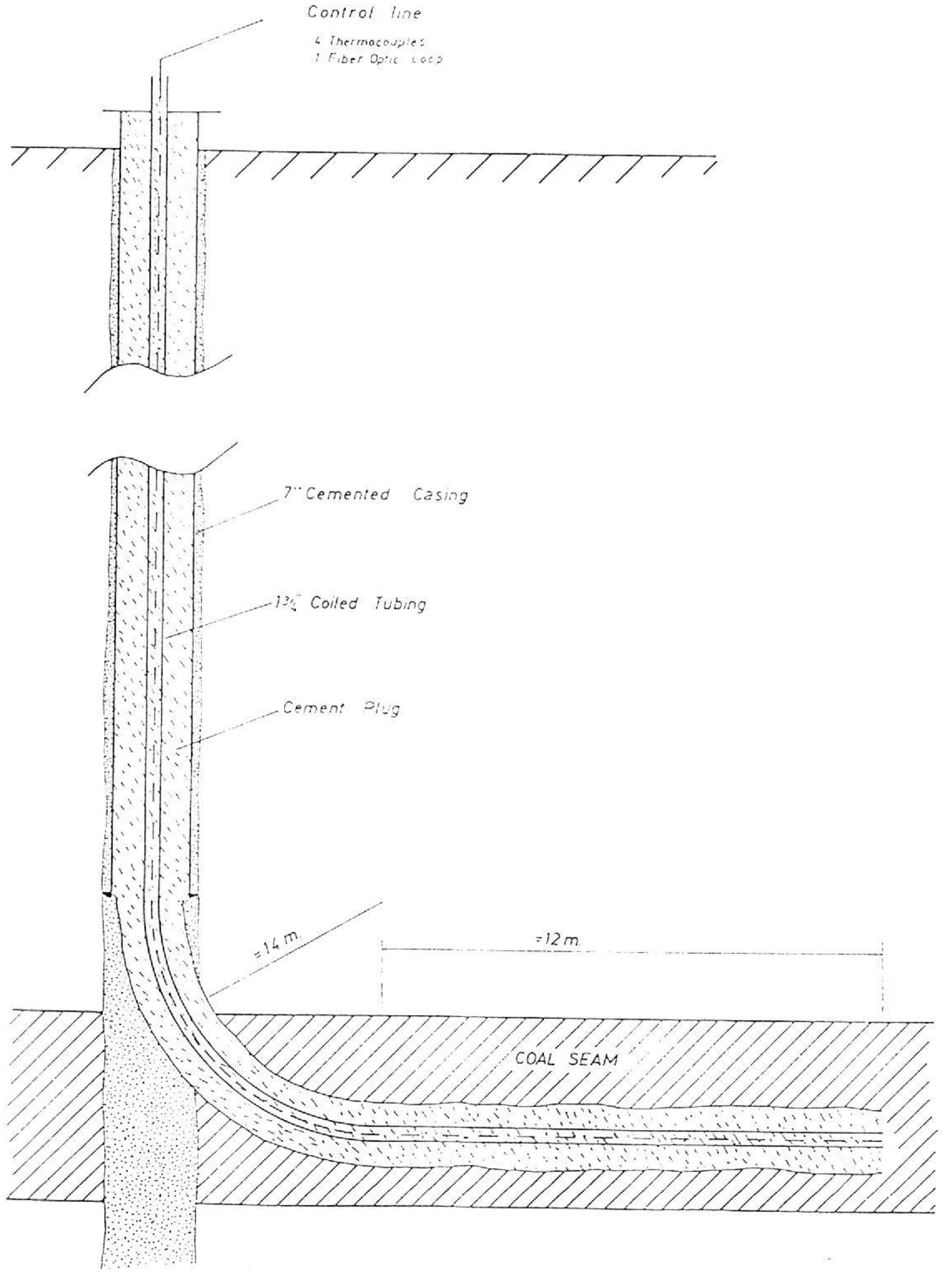

Figure A-6 . Deviated Monitoring Well Completion(MW2)

APPENDIX B

STRATEGY AND DESCRIPTION OF THE PROCESS PHASES
(EL TREMEDAL UCG FIELD TRIAL)

A) General Strategy

The objectives of the field trial are to test/compare two gasification processes(channel gasification combined with CRIP manoeuvre and reverse combustion/pyrolysis followed by filtration gasification) and to determine for each process the operational parameters such as reactor lifetime, cavity growth mechanisms, sweep efficiency, energy efficiency, gas quality.

To realise gasification in the two processes, a strategy of operational phases will be necessary to prepare the first gasifier, to transfer from the first gasifier to the second gasifier, and to switch off/vent the whole system after gasification. Figure B-1 presents the complete sequence of process phases. The process phases start with the process wells under water conditions and ready for gas pressure conditions(all the wellheads and surface plants installed and connected), and finish at the completion of the trial with the wells refilled with water and the wellheads ready for dismantling.

B) Process phase description

a) Water Communication Phase(Phase 1)

The objective of this phase is to check the quality of the final connection between the in-seam end section of the injection well(IW1) and the recovery well(RW) under water conditions prior to initiation of the process phases. To achieve this objective, it is planned to realise water injection inside the coiled tubing string of the deviated in-seam injection well(IW1) and to recover the water by the small tubing string of the recovery well(RW). The other well connections(annular spaces, macaroni, water pipes) of both wells will be kept under very small water flow control to avoid back flows at the bottom of the wells. The transverse vertical injection well(IW2) will be kept under water stand-by conditions.

The hydrodynamics parameters of the test will indicate the quality of the final linking(pressure drop at different flow levels, recovery rate, water influx). An additional tracer test(stimulus-response technique – Sub-phase B) with heavy water is also planned to determine the global flow distribution(residence time, volume/distance, permeability). The total duration of the phase is approx. 2 - 3 days.

The final separation between the injection and recovery wells will depend on the steering capability in drilling the recovery well. The achievable separation between these two wells is expected, with the actual state of the art drilling techniques, to be approx. 1 – 3 metres. An attempt to improve the final linking permeability(virgin coal permeability = 2 md) by high pressure water breakthrough(high pressure water injection inside the deviated injection well) will be realised after drilling the recovery well before casing/liner installation/cementing operations.

b) Water-Nitrogen Exchange Phase(Phase 2)

The objective of this phase is to exhaust water in the in-seam injection well(IW1) and the recovery well(RW) and to prepare the underground reactor for high pressure gas conditions(in equilibrium with the strata fluid pressure at the reactor depth = 50 – 60 bar).

The operations of this phase will be realised in three successive sub-phases:

– Water Column Exhaust –
Water Column Blow-off –
Water-Nitrogen Lift

- **Water Column Exhaust(Sub-phase A}**
In this operation, the water column of each well(IW1 and RW) will be pushed to the bottom level of the recovery well small tubing by nitrogen injection. The control of these operations will be different in each well: in the injection well(IW1), injection of nitrogen will be realised in parallel in all the fluid connections of the well(casing, tubing, coiled tubing and macaroni); in the recovery well(RW), injection of nitrogen wili be realised in parallel in all the fluid connections(casing, water pipes, insulated tubing, macaroni) except the small tubing string used for water exhaust. The fact that the water column exhaust from the injection well will be made through the final linking section before reaching the recovery well bottom is another significant difference of the operation conditions in the two wells and could lead to a larger pressure drop and longer operation duration at the level of the injection well. The volumes of the injection well(IW1) and the recovery well(RW) will be respectively = 24 m3 and = 30 m3 . The total duration of these operations is 12 – 24 hours.
- **Water Column Blow-off(Sub-phase B)**
This part of the water-nitrogen exchange process is a very short transitory phase. The situation will arise when the remaining water column inside the small tubing of the recovery well(RW) looses its water column pressure stabilising effect and non-stable blow-off conditions are encountered. During this phase, the counter-pressure valve at the recovery well wellhead must

react to the quick increase of flow and pass from the water column counter-pressure(atm. pressure) to the gas condition counter-pressure(= 60 bar). The internal volume of the small tubing will be approx. 0.6 m3. The duration of this phase will be some minutes.

- **Water-Nitrogen Lift(Sub-phase C)**
  The objective of this sub-phase is to dry the wells(IW1 and RW) and the final linking section between the two wells. Because of the depth, water removal will be by nitrogen lift. The lift system depends on the flow regime inside the pipe, the best flow regime to realise it being the annular-mist regime. With a bottom hole counter pressure of 50 to 60 bar, a minimum flow of 400 – 450 Nm3/h is necessary to install this regime inside the 1.66" small tubing string. The duration of the phase is a function of the drying conditions: a water flow below 10 litres per hour will be acceptable, Probably, 1 – 2 days will be necessary to reach this condition.

The transverse vertical injection well(IW2) will be kept under water stand-by conditions, as for Phase 1.

c) Nitrogen Communication Phase(Phase 3)

The objective of this phase, similar to the objective of Phase 1, is to check the quality of the final connection between the in-seam end section of the injection well(IW1) and the recovery well(RW) under gas flow conditions. This phase will be very important to assess the value of the final linking phase(Phase 4).

To achieve this objective, it is planned to realise nitrogen injection inside the coiled tubing string of the injection well(IW1) and to recover the nitrogen by the small tubing string of the recovery well(RW). The counter-pressure used will be the pressure of the subsequent gasification phases(= 50 – 60 bar). Other well connections(annular spaces, macaroni, water pipes) will be kept under low nitrogen flow control to avoid back flows at the bottom of the wells. The nitrogen lift conditions will also be maintained inside the small tubing of the recovery well.

The transverse vertical injection well(IW2) will be kept under water stand-by conditions. The hydrodynamics parameters of the test will indicate the quality of the final linking(pressure drop at different flow levels, recovery rate, water influx). An additional tracer test(Sub-phase B) with helium is also planned to determine the global flow distribution(residence time, volume/distance, permeability). The total duration of the phase is approx. 2 – 3 days.

d) Final Linking Phase(Phase 4)

This phase is optional and will depend on the results of the nitrogen communication phase. If the permeability of the final section between the injection well(IW1) and the recovery well is high enough the ignition and CRIP manoeuvre phase(Phase 5) will be started immediately, if not, a reverse combustion process will be started from the recovery well to try to improve the final linking.

The reverse combustion process implies three consecutive sub-phases:

- The injection /ignition operations
- The flow inversion/decompression operations
- The reverse combustion operations

- **Injection/ignition operations(Sub-phase A)**
  This sub-phase will require an injection of air(low flow of Op plus Np) inside the coiled tubing string of the injection well(IW1) and the insulated tubing string of the recovery well(RW). The other connections of both wells(mainly at the recovery well - pressure change from 50 bar to injection conditions = 100 – 150 bar) will be maintained under nitrogen flow /pressure control to avoid back flow of air inside the annular spaces. When the injection conditions on both wells are stabilised, the bottom hole igniter of the recovery well will be started to pre-heat the air injected around the well. The control of the temperature of the preheated air will be realised by the control of the power delivered by the burner(Op and CHp flows/burner tip temperature control). The self ignition of the coal surrounding the well will be observed after a certain time by an increase of the injection pressure(volume increase by temperature effect and partial blockage of the coal fissure system by combustion liquid products deposition). The termination of the phase will be decided on the basis of evaluation of the quantity of coal burned around the recovery well(mass balance calculation based on the cumulative air flow from the time of coal ignition).
- **Flow inversion/decompression operations(Sub-phase B)**
  After ignition of the coal in the vicinity of the recovery well, this transitory phase will serve to decompress the recovery well after injection and to establish the reverse combustion process. A continuous low flow of air will be injected inside the coiled tubing string of the injection well(IW1) and the small tubing pressure release valve will be progressively opened to start well decompression. Careful attentions must be given to the recovery well(RW) bottom temperature during these operations by adjusting the decompression flow. First, the analysing unit will detect the combustion gas coming from the recovery well(RW) vicinity. Secondly, if reverse combustion starts with the air coming from the injection well(IW1), the first reverse-combustion products will appear. During the following checking period, the Op content of the reverse combustion products will be carefully analysed to determine if the reverse combustion process has started successfully. If not, the first two operations will be repeated.
- **Reverse combustion operations(Sub-phase C)**
  This part of the operation is the reverse-combustion proper. The objective of this phase is to increase the permeability of the final linking by channel formation between the recovery well(RW) and the in-seam injection well(IW1). The normal

velocity of the process is about 1-2 metres per day.

The process will be initiated with air(= 50 – 100 Nm3/h) and a counterpressure similar to the gasification pressure(= 50 - 60 bar). Some change in the reverse-combustion parameters(Op content, flow at the injection well and counter-pressure at the recovery well) may be tried to control the process(velocity, size of the channel formed). The small tubing of the recovery well(RW) will be used to exhaust the reverse combustion products and the lift system will be maintained

The transverse injection well(IW2) will be kept under water stand-by conditions. The remaining annular spaces, macaroni, water pipes of the wells(IW1, RW) will be kept under low nitrogen flow control to avoid back flows at the bottom of the wells. Particular attentions must be given to the control of flows/pressures within annular spaces because these contain relatively high volumes of compressible gas at high pressure(60 to 150 bar).

e) Ignition and CRIP Manoeuvre Phase{Phase 5}

Immediately following the reverse combustion phase or the nitrogen communication phase if the final linking permeability is high enough, the channel gasification process will be initiated by an appropriate positioning of the ignition/injection head of the coiled tubing inside the in-seam section of the injection well(IW1) and/or starting of the burner to destroy the liner in the gasifier zone.

To control start-up, two different operation conditions are possible:

– Positioning the igniter/injection head at an appropriate location. Starting of the burner. Creation of a window through the liner by burner action(Sub- phase A). During this phase, air will be injected inside the coiled tubing and OpICHg will be injected inside the macaroni. Operations will be controlled with the help of fibre optic and thermocouple measurements(tip of the burner and liner). The duration of this phase depends on the window creation and will be 1 – 2 hours. Retraction of the injection head(burner switch-off). Control of the back burning of the liner by Op injection through the Op macaroni(Sub-phase B).
The duration of this phase depends on the liner back burning conditions and will take approx. 1 - 2 days for a length of 25 - 30 metres.

The sequence of actions is different depending on whether operations begin directly from the reverse combustion phase or the nitrogen communication phase:

-Directly from the reverse combustion phase.
Progressive increase of Op content(starting from the reverse combustion

Op/Np ratio to pure Op) and progressive backward displacement of the injection head(= 1 metre per hour) until the first cavity injection position(= 33 m from the recovery well). During this period, the reverse burning of the carbon steel liner will take place by Op injection and be measured by the fibre optic /thermocouple along the liner. A starting of the burner may be foreseen at the end of the phase to fix the final injection point of the gasification process. After this, the injection head of the coiled tubing(burner switch-off) will be put in a safe position and the channel gasification phase(Phase 6) will be started progressively.

-Directly from the nitrogen communication phase.

First, the starting of the burner situated at the final position of the in-seam section of the injection well will be realised to test the behaviour of the final linking under small flow air gasification conditions. Following, a progressive increase of the Op content(to pure Op) and a progressive backward displacement of the injection head will be realised. The remaining actions will be similar to those in the previous sequence(directly from reverse combustion phase).

The small tubing string of the recovery well(RW) will be used during the final linking phase to exhaust the liner combustion/coal gasification products. Due to the low flow conditions, some injection of nitrogen may be realised to maintain the water removal by lift system. The counter-pressure will be set to 50-60 bar. The second injection well(IW2) will be maintained under water stand-by conditions.

Two other ignition and CRIP manoeuvres are planned with position of the injection points at 2/3 and at the total length of the in-seam injection well section(liner of = 100 metre length). The remaining annular spaces, macaroni, water pipes of the wells(IW1, RW) will be kept under low nitrogen flow control to avoid back flows at the bottom of the wells.

f) Channel Gasification Phase(Phase 6)

The objective of the channel gasification phase is to operate for 20 – 40 days with an average coal gasification rate of up to 100 tonnes per day and to collect the maximum information on operational parameters. Capability to relocate the injection point by CRIP manoeuvre after a decline in gas quality will be also tested. Two or three CRIP manoeuvres are planned.

Before injecting HpO/Op, the reactor will be started/stabilised with air injection over 1 - 2 days(Sub-phase A). The flow of air will be in the range 200-500 Nm3/h.

After the stabilisation period, injection will be switched to HpO/Op conditions(Sub-phase B). The baseline of these channel gasification conditions will be 1000 Nm3/h oxygen, 1.5 HpO/Op molar ratio and 50 bar counterpressure. The flow condition of 1000 Nm3/h oxygen will be reached progressively during the cavity growth. Higher flow conditions(up to 1500 Nm3/h) may be tried at the maximum cavity development. The counterpressure will be adjusted around the strata fluid pressure(50 - 60 bar) following information on water influx/gas losses. The HpO/Op ratio will also be adjusted in the range of 1 to 2.

Some helium tracer tests(Sub-phase C) will be realised during the cavity growth. A continuous injection(very low flow - 0.1% of the Op flow) of argon inside the gasification agents will also be made to facilitate the mass balance calculation. The transverse injection well(IW2) will be maintained in water stand-by conditions. Flow must be carefully controlled in the well during this phase because the enlargement of the cavity may have a significance influence(sharp increase of the permeability around the well, fissure/fracture creation).

Due to the high flow conditions of this phase, the product gas will be conducted through the insulated tubing string and/or the small flow tubing string of the recovery well(RW). Some cooling action with water may be needed during the cavity development to prevent excessive temperature at the bottom of the recovery well(RW)(temperature control at 300 - 350 °C).

g) In-seam to Transverse Phase(Phase 7)

The objective of this phase is to transfer progressively the process control from the in-seam injection well(IW1) to the transverse injection well(IW2). The first operation(Sub-phase A) will be a drainage of the water content of the transverse injection well(IW2) through the coal seam and through the cavity created during the channel gasification phase by nitrogen injection inside all the fluid connections of the well(casing, tubing, macaroni).

The power of the channel gasification will also be progressively diminished during this phase by flow reduction(1000 - 1500 Nm3/h to 100 - 200 Nm3/h) and switch over air conditions. The second operation(Sub-phase B) will consist of the transfer of air injection from the in-seam injection well(IW1) to the transverse injection well(IW2) and the setting of the in-seam injection well(IW1) under nitrogen stand-by conditions(low flow of nitrogen).

As a consequence of the decrease of flow, the product gas may be conducted through the small tubing string of the recovery well and the water removal by lift system regained by nitrogen injection through the insulated tubing annular space.

h) Reverse Pyrolysis/Combustion Phase(Phase 8)

The objective of this phase is to increase the permeability of the zone between the transverse injection well(IW2) and the already gasified area(channel gasification phase) by initiating a reverse pyrolysis /combustion process from the previous hot gasifier zone.
The process will be initiated with air(Op plus Np = 200 – 300 Nm3/h) and a counter-pressure similar to the previous counter-pressure(= 50 - 60 bar). Some change in the reverse pyrolysis/combustion parameters(increase of the Op content up to 40 %, increase of the injected flow up to 700 – 1000 Nm3/h and counter-pressure decrease at the recovery well(RW)) may be tried to control the process(velocity, size of the channel formed and flow distribution conditions).

The reverse pyrolysis/combustion products will be exhausted by the small tubing string of the recovery well(RW) and the lift system will be maintained by nitrogen injection through the insulated tubing annular space. If the injection flow is increased up to 700 – 1000 Nm3lh, the exhaust of the product gas may be switched to the insulated tubing of the recovery well(RW). The duration of this phase will be 15 – 20 days.

i) Filtration Gasification Phase(Phase 9)

This phase is optional and will depend on the results of the reverse pyrolysis/combustion phase. If the permeabilty of the intermediate zone between the transverse injection well(IW2) and the channel gasification area at the end of the reverse pyrolysis/combustion phase is high enough, the filtration gasification process will be initiated. The objective, similar to that of channel gasification, is to operate for 20 – 40 days with an average coal gasification rate of up to 100 tonnes per day and to collect maximum information on the operational parameters of the process.

Before starting with the HpO/Op injection, it is also planned to continue after reverse pyrolysis/combustion in forward mode with air injection(200 - 500 Nm3/h) to stabilise the reactor(Sub-phase A). The duration of this phase is 1 -2 days.

The igniter located at the bottom of the tubing string may be started to reinitiate the combustion of the coal at the proximity of the transverse injection well(IW2)(Sub-phase B). The control of the temperature of the injected air will be realised as during the injection/ignition sub-phase of the final linking phase by the power delivered by the burner(Op plus CHp flows/burner tip temperature control).

After the stabilisation period, injection will be switched to HpO/Op conditions(Sub-phase C). The baseline of the filtration gasification process will be set at 1000 Nm3/h oxygen, 1.5 HpO/Op molar ratio and 50 bar counterpressure. The flow condition of 1000 Nm3/h oxygen will be reached progressively during the cavity growth. Higher flow conditions(up to 1500 Nm3/h) may be tried at the maximum cavity development. The counterpressure will be adjusted around the strata fluid pressure(50-60 bar) following information on water influx /gas losses. The HpO/Op ratio will be also adjusted in the range of 1 to 2.

Some helium tracer tests(Sub-phase D) will be realised during the cavity growth. A continuous injection(very low flow - 0.1% of the Op flow) of argon within the gasification agent will be made as a control for the mass balance calculation. The in-seam injection well(IW1) will be maintained under nitrogen stand-by conditions. Careful attention must be given to the flow/pressure control of this well.

Due to high flow conditions again, the product gas will be conducted through the insulated tubing string and/or the small tubing string of the recovery well(RW). Some cooling action with water may be needed during cavity development to prevent excessive temperature at the bottom of the recovery well(RW)(temperature control at 300 – 350 °C).

j) Shutdown and Nitrogen Venting Phase{Phase 10)

When a decline in gas quality is observed, the gasification process will be shutdown with injection of nitrogen in all connections to the injection wells(IW1 and IW2) and all connections to the recovery well(RW) except for the small tubing used for gas exhaust. Operations will continue for 5 – 7 days to vent the underground reactor with nitrogen.

k) Nitrogen-Water Exchange Phase(Phase 11)

At the end of nitrogen venting, the underground reactor will be filled with water by injection in all the well connections except for the small tubing of the recovery well. Water injection will be maintained over 1 – 2 weeks.

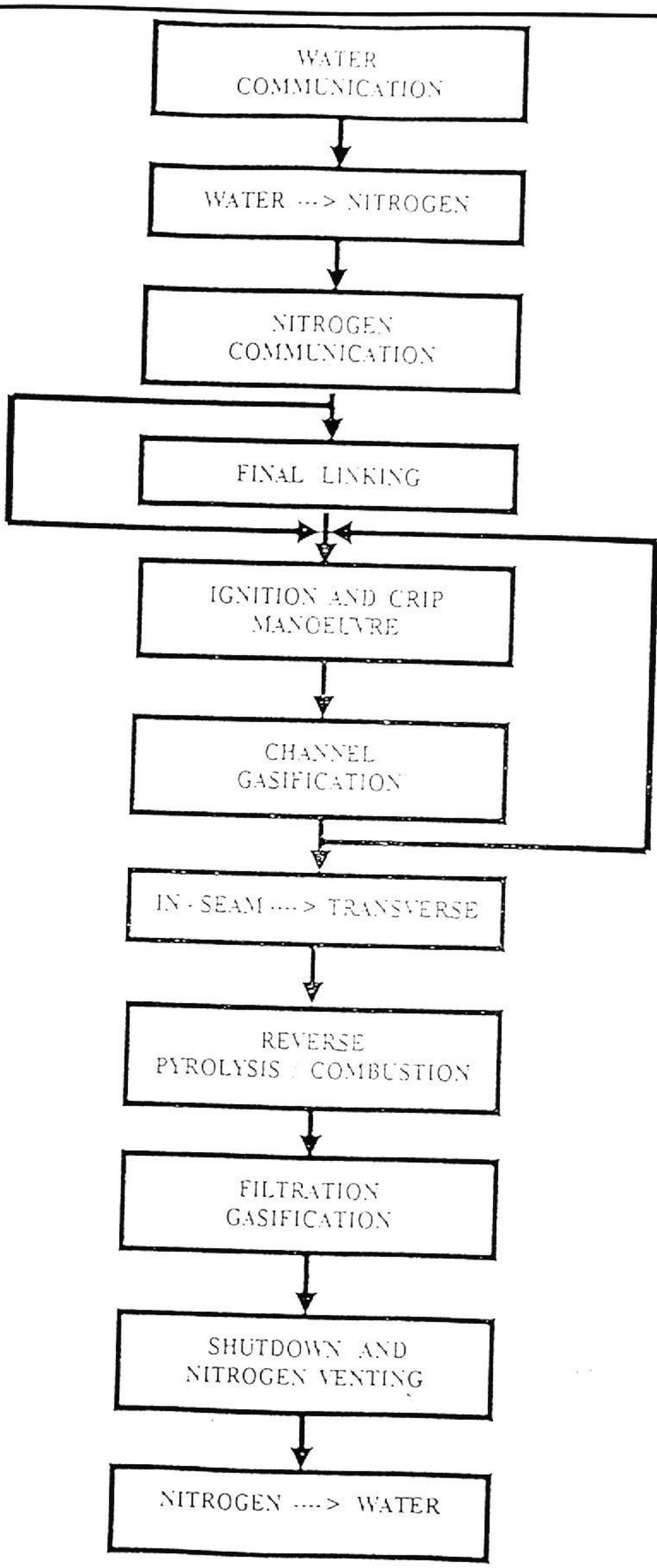

Figure B-1 . Process Phase Sequence