

## RESEARCH ON THE COAL BENEATH THE NETHERLANDS

## IV – NEW PRODUCTION METHODS

## 4. UNDERGROUND COAL GASIFICATION WITH HEAT RECUPERATION

D.N. DIETZ<sup>2</sup> & J. BRUINING<sup>2</sup>

## ABSTRACT

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Gasification of coal occurs at high temperatures. The energy present in the coal, as far as it is not converted into the chemical energy of the gas produced, is liberated in the form of sensible heat. This heat will be carried along by the gases and is partly lost to the cap and base rock of the thin coal layer; the rest of this heat is carried off through a production well. During the cooling process, part of the combustible gas will be reconverted into non-combustible components. This generates further heat. All this heat represents an important part of the energy originally present in the coal. This part can approach values of 100% under unfavourable process conditions or even more than 100% if steam is injected. Because coal in The Netherlands occurs in thin layers and at great depth only small amounts of this sensible heat can be recuperated at the surface.

By adapting a heat recuperation method from the oil technology we aim to transfer the heat left upstream of the reaction zone back to this process zone, to accomplish a more efficient gasification process and to avoid excessive temperatures in the production well.

## INTRODUCTION

The coal layers in The Netherlands are thin and located at great depth. Production of this coal therefore is fraught with technical problems. The advantage of great depth, however, is that gasification can be carried out at high pressures. Equilibria at high pressures favour methane production. Moreover, at higher pressure reaction rates are higher and contact times are longer. Therefore with the thin and deep coal layers of the Netherlands we are not necessarily worse off than with the thick and shallow layers elsewhere but we do have some specific problems of our own.

The disadvantage of thin layers is that relatively more area is available from which heat is lost. This reduces the quality of the gas. Any energy lost in the form of sensible heat cannot contribute to the chemical heat content of the gas produced.

This argument is confirmed by the codes of practice used by the Russians.

'The quality of the gas produced from thin layers (< 1 m) is unusably low' (EDGAR, 1981). A remedy proposed by Dietz (DIETZ, 1973; DIETZ & BRUINING, 1980; DIETZ & WEYDEMA, 1972) can be used to recuperate part of the heat lost to cap and base rock and to transfer this heat back to the process zone. The method is based upon experience with underground oil combustion for enhanced oil recovery. We expect two advantages of this method:

1. decrease of heat losses
2. temperature control to avoid damage to wells

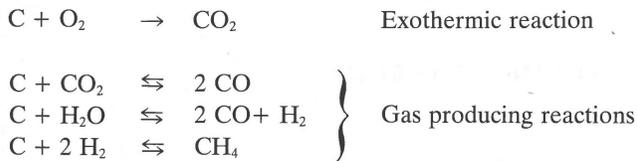
## PRINCIPLE OF UNDERGROUND GASIFICATION

Underground gasification is usually carried out by the injection of air, sometimes with steam. The injection well is connected to a production well via the coal layer (Fig. 1). After ignition the following reactions occur, further formulae being redundant for a thermodynamic description.

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<sup>2</sup>Delft University of Technology, Dept. of Mining Engineering, Mijnbouwstraat 120, 2628 RX Delft, The Netherlands.



The gaseous products thus formed leave the layer via a production well. An important difference with gasification above ground lies amongst other things in the scale. In order to get an idea of the dimensions involved, one should divide the lengths of the model shown in Fig. 2 by one thousand. In this scale model the coal layer has dimensions of 14 cm x 14 cm and a thickness of 1 mm. The wells have a diameter of 0.3 mm and a length of 1.50 m, corresponding to a depth of the coal layer of 1500 m.

As far as heat losses are concerned the time scale is reduced quadratically as compared with the dimensional scale reduction i.e. by a factor of a million. An assumed project time of 1000 days in reality means therefore about 86 seconds for the 1:1000 scale model of the situation shown in Fig. 2.

### HEAT LOSSES

Heat losses in the injection well occur only if steam is injected. These losses represent at least a few percent of the energy stored in the coal layer. On the other hand, the steam lost on its way down the well may be many times the steam effectively injected at the bottom. The cumulative heat losses from a cylindrical well are almost proportional to the project time. The project time, however, cannot be made arbitrarily short. The reason is that the gases have to stay a finite time in the reaction zone in order to give them sufficient opportunity to react and thus to obtain a reasonable conversion to combustible products (LEVENSPIEL, 1972). Therefore, the optimum

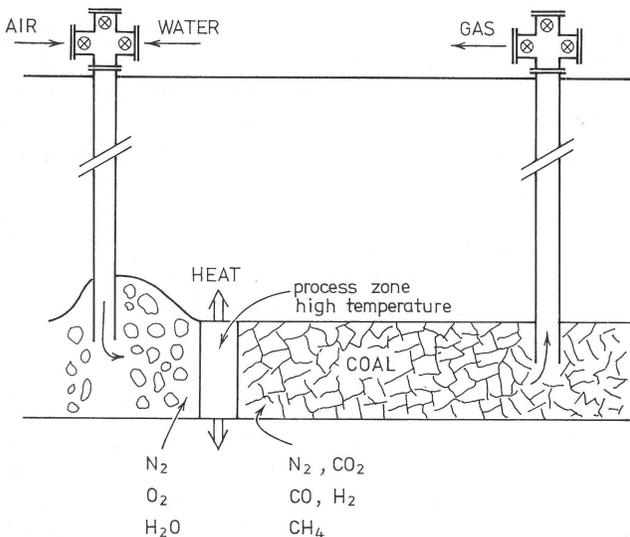


Fig. 1 Principle of underground gasification.

project time depends on the reaction rates and transport processes that occur during underground gasification. If besides air, steam is injected a large part of the steam will condense during the long path travelled in the injection well (Fig. 2).

For shallow layers, such heat losses are smaller, because they are proportional to the length of the well. Although the amount of condensing steam may be acceptable for shallow

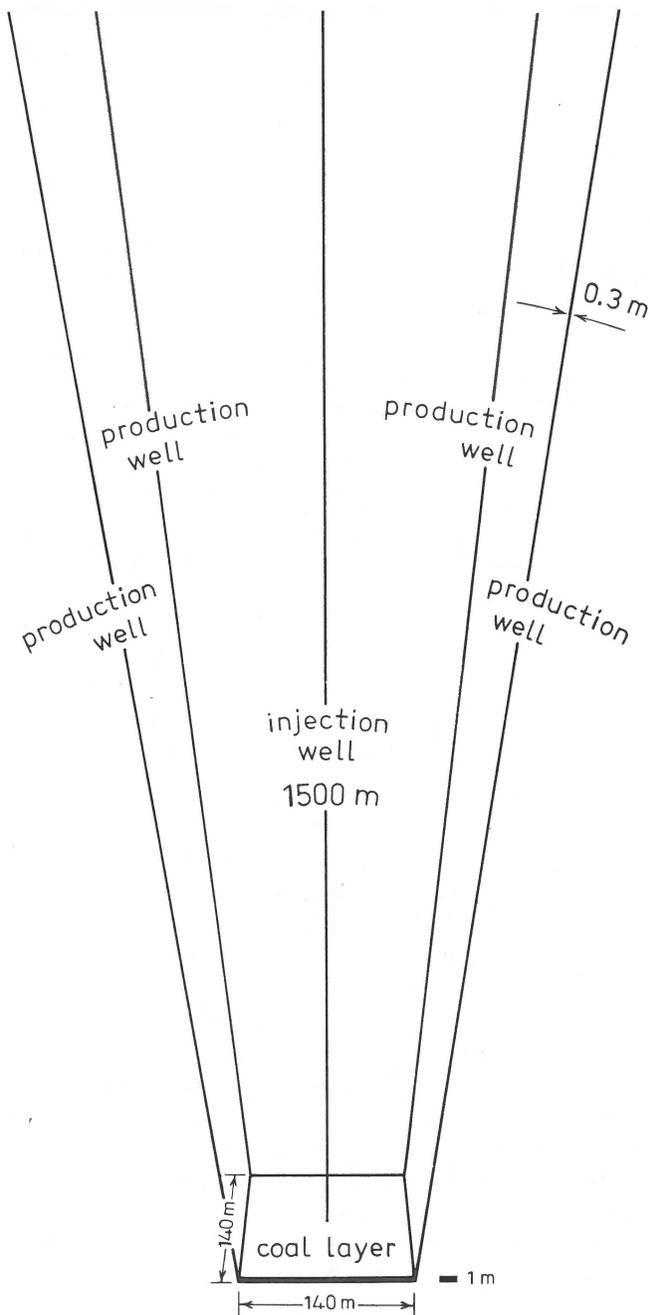


Fig. 2 Model of underground gasification to illustrate the peculiar relationship between the occurrence of Dutch coal in thin layers and its production from great depth. Thickness of the coal layer is 1 m.

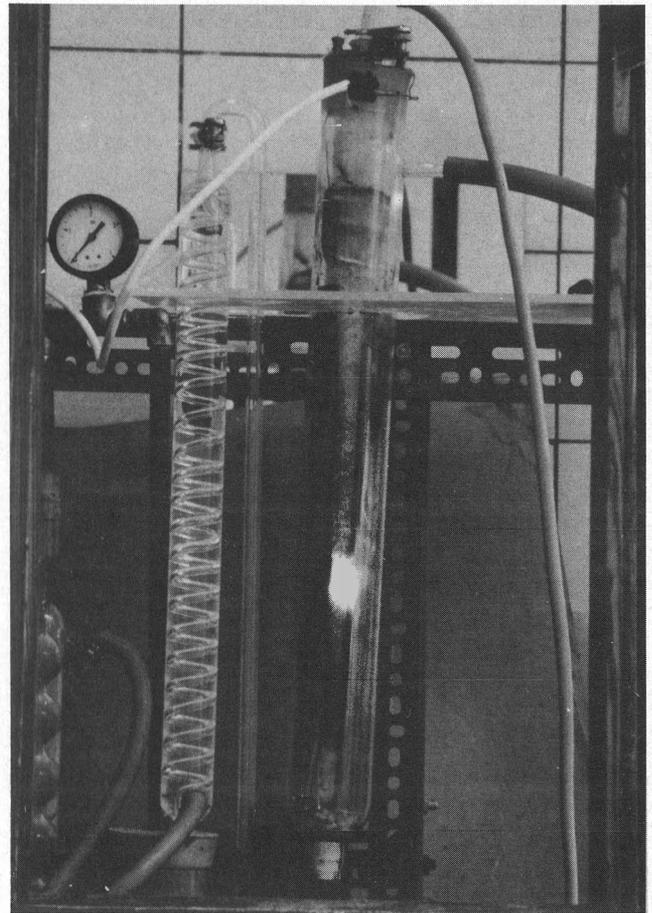
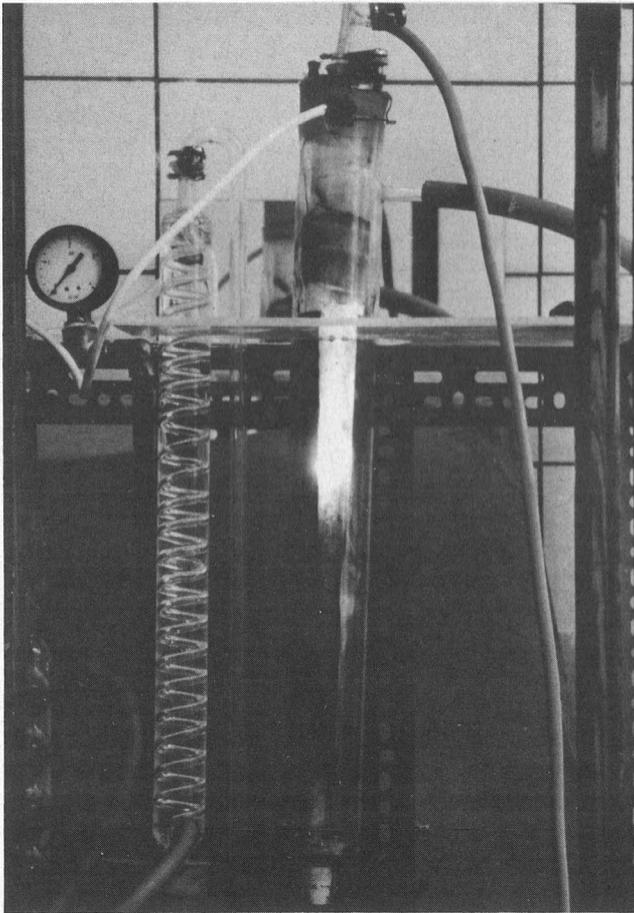


Fig. 3  
 (left) Quartz tube with conventional gasification; long hot zone, great heat loss. The heat balance determines the mixture of flue gas and fuel gas.  
 (right) Quartz tube for gasification with heat recuperation; short hot zone, less heat loss, less air injection: production of more fuel gas.

layers such as occur in the United States, they are certainly not acceptable if the hot water point (the point where all the steam has condensed to water) is located above the bottom of the injection well (SATTER, 1972). When the air injected reaches the hot coal layer, combustion occurs. After the oxygen has been consumed gas producing reactions occur further downstream. The heat will be partly lost to the cap and base rock. As the temperature of the gas declines, the system tends to counteract this temperature decrease and part of the combustible gas will be reconverted to noncombustible components. Part of the heat thereby liberated will be lost to the cap and base rock. The remaining heat will reach the production well. Apart from corrosion effects heat will be lost from the production well into the adjacent formations. Moreover the iron of the tubing in the well will catalyze the reconversion reaction from combustible carbon-monoxide to non-combustible carbon-dioxide at temperatures as low as 400-500 C (EDGAR, 1981). Most of the heat liberated during this reaction will be lost from the well.

Efforts to recover the sensible heat generated during the gasification process at the surface, will therefore be more successful for thick coal layers at rather shallow depth. Heat

recovery at the surface will, however, not give a significant contribution to the amount of energy extracted from gasification of thin layers at great depth.

#### TEMPERATURE CONTROL

A possible remedy to reduce heat losses is by underground heat recuperation (DIETZ, 1973; DIETZ & BRUINING, 1980; DIETZ & WEYDEMA, 1972). This can be achieved if the length of the process zone can be controlled. The principle of the method is illustrated with a quartz tube experiment (Fig. 3) and with a computer simulation programme (Fig. 4).

In Fig. 3 two experiments are shown. The photograph on the left hand side shows a quartz tube through which air is injected from above. Product gases are collected at the bottom of the tube. An expanding hot reaction zone develops. The length of this zone is chosen to give sufficient time for the gas producing reactions to occur. A large reaction zone means great heat losses so that less energy remains to contribute to the (chemical) energy content of the gases produced.

The right hand side photograph in Fig. 3 shows the same

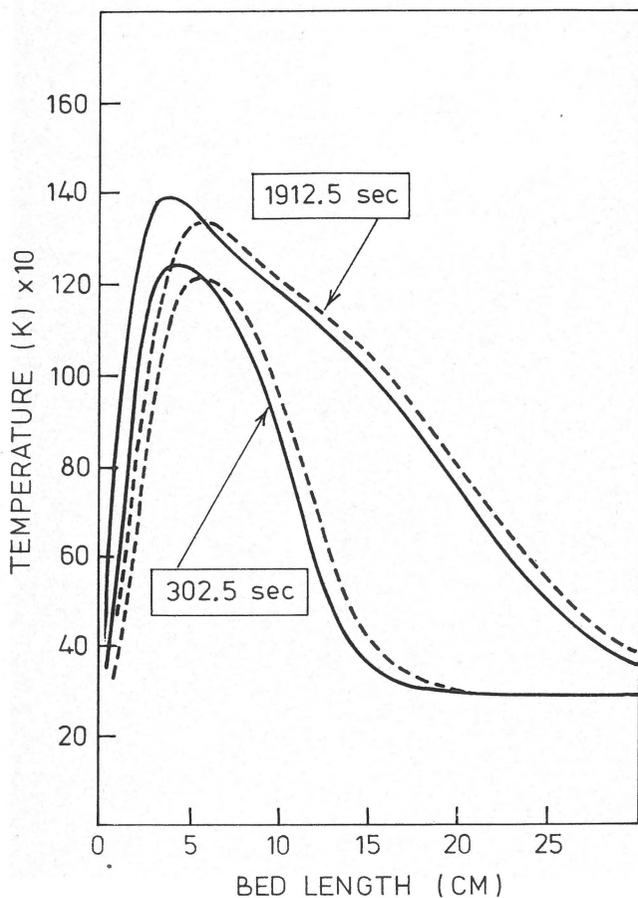


Fig. 4  
Temperature profiles with air injection only. After ignition the temperature wave expands towards the injection well and its length increases (see text).---- gas temperature, - coal temperature.

quartz tube while water is injected in addition to air. The length of the reaction zone has become smaller. Its length can be controlled by decreasing or increasing that water/air injection ratio. A shorter reaction zone means less heat loss and more energy available for the chemical energy content (quality) of the produced gas.

Figs 4 and 5 show the results of a computer simulation programme, adapted from one used at the University of California, by incorporating liquid water injection (THORNESS, 1978). The dynamic programme is based upon the various conservation laws written in terms of partial differential equations, temperature dependent reaction rate equations, limitations of reaction rates by diffusional processes (LEVEN-SPIEL, 1972) etc. The dimensions shown correspond to the dimensions of a tube experiment to simulate underground gasification.

At first we shall follow the temperature profile if air is injected only (Fig. 4). Ignition of the coal layer occurs at some distance from the injection well (GJBELS, 1982). There are two kinds of temperature curves, one kind for the gas temperature and another for the coal temperature. The gas takes up heat

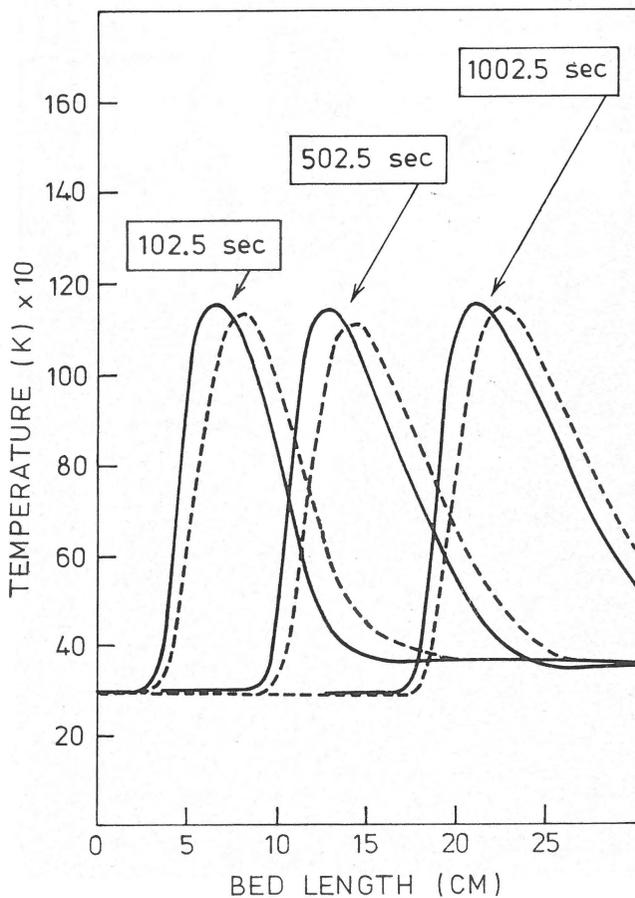


Fig. 5  
Temperature profiles with combined water and air injection. After ignition water is injected in addition to air and the temperature wave moves away from the injection well. The length of the wave remains constant.---- gas temperature, - coal temperature.

from the coal and therefore its temperature wave is displaced slightly downstream with respect to the solid temperature wave. After ignition the side of the temperature curve facing the injection well starts to move upstream or countercurrent to the flow of air. This is called 'reverse burning' and it may cause damage to the injection well. The part of the temperature wave facing the production well moves downstream with the flow of gases. Therefore the temperature wave expands, that is, its length increases.

After heating the coal layer, the hot gases enter the production well. In Fig. 5 we observe the behaviour of a temperature wave if heat recuperation techniques are applied. After ignition a temperature wave develops again at some distance from the injection well. Before the temperature approaches the injection well, however, cold water is injected in addition to air (in this case a relatively high molar water/air ratio 2 : 1 was applied for illustration purposes).

In the field water and air will be injected in alternate batches to avoid corrosion of the injection well. Contrary to the behaviour when only air is injected, the whole temperature wave moves downstream with the flow of gases, while its

length remains more or less constant. The velocity of the upstream part of the temperature wave, facing the injection well, is no longer determined by the rate of coal consumption. Consequently only part of the coal will be gasified if the temperature wave travels once from the injection to the production well (i.e. in one sweep). All of the coal will be gasified, however, in a few consecutive sweeps of the temperature wave. This leads to the additional advantage of a more gradual subsidence.

We have shown that temperature control is in principle possible by cold water injection. In this way a better quality gas can be produced and excessive temperatures in the production well can be avoided. The method will be further elaborated with the help of high pressure tube experiments in order to obtain quantitative results such as:

1. optimum length of the temperature wave
2. optimum gasification temperature and pressure
3. optimum water/air injection

### CONCLUSION

Heat losses play an important part during underground gasification of thin coal layers located at great depth such as

present in The Netherlands. Methods to recuperate the heat underground by cold water injection constitute a possible remedy. In this way a better quality gas may be produced and the length of the temperature wave may be controlled. Excessive temperatures in the injection- and production wells can be avoided.

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