© 1982 Geologie en Mijnbouw 0016-7746/82/6104-0377 $ 2.50/0

RESEARCH ON THE COAL BENEATH THE NETHERLANDS

IV – NEW PRODUCTION METHODS

2. STABILITY OF AN UNDERGROUND COAL GASIFICATION CAVITY[1]

J.P. VAN BAAREN[2] & J. KETTING[2]

ABSTRACT

Van Baaren, J.P. & J. Ketting 1982 New production methods. 2 Stability of an underground coal gasification cavity. In: J.J. Dozy (ed.): Research on the coal beneath The Netherlands – Geol. Mijnbouw 61: 377-381.

A concept for coal gasification of deep lying thin coal layers via borehole linking and repeated sand-fill of the reaction chamber is described. The influence of high temperatures (up to 1000° C) on the rock properties are summarised. The stability of a borehole leading to an underground coal gasification chamber can be simulated by means of a finite element computer programme. Forthcoming research on this subject for the next 3 years is indicated.

INTRODUCTION

The article consists of two parts. In the first part work performed by Grupping (1978) is briefly described, explaining the process of coal gasification of dipping coal layers. The second part deals with the study under review. Its objective is to predict the behaviour of the rock mass enclosing a boring or a reaction chamber under increasing temperature. The present work and the article deal with a hole entirely in country rock.

COAL GASIFICATION OF DIPPING COAL LAYERS

In the process of gasifying deep lying and thin coal layers several problems arise. A number of these problems can be solved by applying the method proposed by GRUPPING (1978). Two boreholes can be drilled with such a deviation that the hole remains over a considerable length within the dipping coal layer. The bottoms of the holes have almost to make contact in order to get a link as shown in figure 1. By air injection in one hole the coal can be gasified and the gases produced can be transported through the other production hole. The gasification of the coal should continue updip for a certain distance after which a sand slurry is brought in to fill the cavity almost entirely.

Dipping underground cavities can be filled with a sand slurry (GRUPPING & PIETERSON, 1981). After removing the water with high pressure gas the gasification can be reinitiated. This cycle can be repeated continuously (Fig. 2).

The procedure has several advantages:

- In general the coal layer will be insufficiently permeable to allow the passage of gas even after fracking.

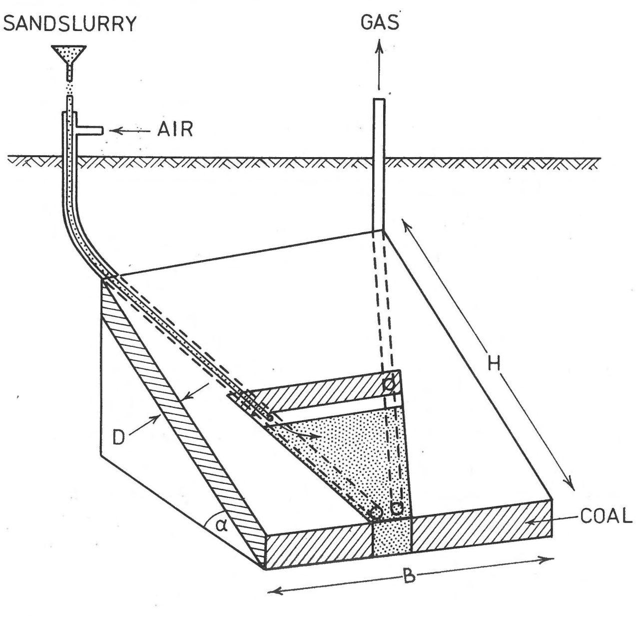

Fig. 1
Underground coal gasification process for dipping coal layers with sandfill method (after Grupping, 1978).

[1]Manuscript received: 1982-08-26.
Revised manuscript accepted: 1982-10-20.
[2]Delft University of Technology, Dept. of Mining Engineering, Mijnbouwstraat 120, 2628 RX Delft, The Netherlands.

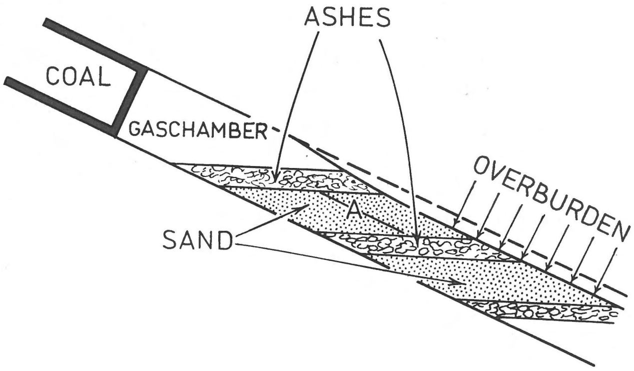

Fig. 2
Cross section through reaction chamber (after Grupping, 1978).

Linking the injection and production holes to initiate a quick coal gasification process is easier if the holes connect.

- Almost filling the reaction chamber with sand will leave a small 'burn' cavity with a good turbulent gasflow. The latter improves the contact between the injected air and the coal.
- The smaller reaction chamber will also prevent too much heat loss to its surroundings.
- The sand fill will support the overburden to a certain degree and counter subsidence.

ROCK MECHANICAL PARAMETERS

The behaviour of the rock around the borehole and coal front can be simulated when the rock mechanical parameters are known (KETTING, 1981). In this section the influence of temperature will be discussed.

The temperature of the country rock in contact with an underground coal gasification cavity is estimated to be 800-1100° C. The high temperature will cause an increase in ductility and a decrease in strength of the surrounding rock. The temperature gradient will cause high thermal stresses. From the literature it is known that the rock properties will change with increasing temperature as follows:

1. The mineralogy of the rock is likely to change chemically under temperatures of say 1000° C. The stresses thereby introduced have an important influence on the strength of the rock.
2. The thermal expansion coefficient increases slightly. AKTAN & FAROUQ ALI (1978), however, observed no significant change for sandstone.
3. The elastic modulus and ultimate strength of the rock will decrease. As an example the stress/strain behaviour of Solnhofen limestone under different temperatures is given in Fig. 3. Other lithologies, E.G. Sandstone, behave similarly. The modulus of elasticity remains strongly reduced after cooling down. (ADVANI ET AL., 1976; ADVANI & GMEINDL, 1979; CLARK 1965).

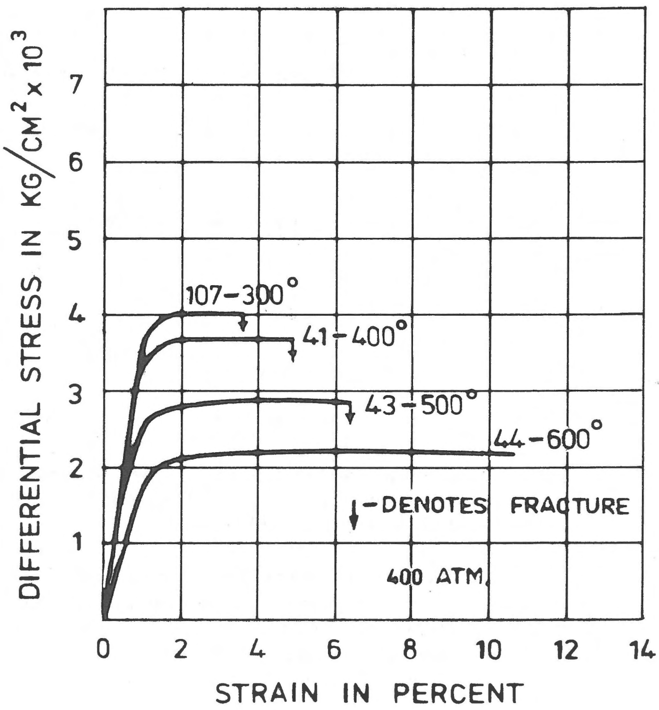

Fig. 3
Compression stress-strain curves at various temperatures for Solnhofen limestone (after Heard, 1960).

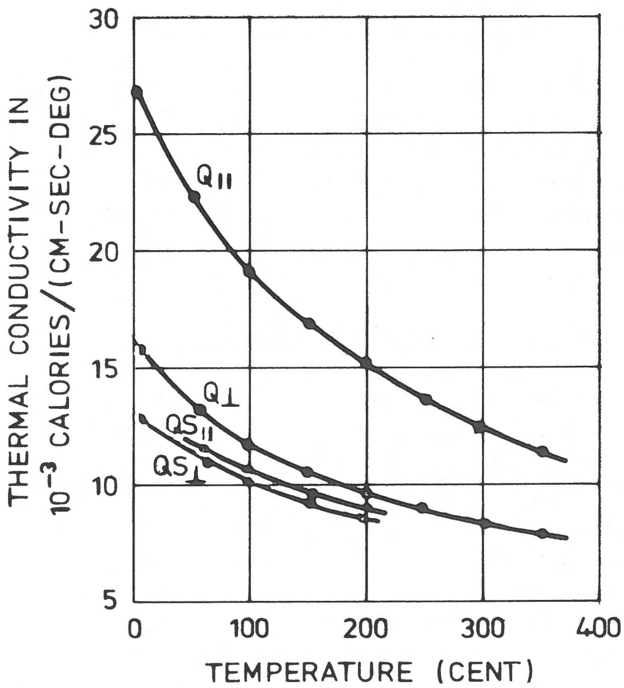

Fig. 4
Thermal conductivity of quartz and of a quartzitic sandstone:
QS⊥ Quartzitic sandstone, Penn., perpendicular to bedding plane
QS// idem, parallel to bedding plane
Q⊥ Quartz, single crystal perpendicular to optic axis
Q// idem, parallel to optic axis
(Birch & Clark, 1940).

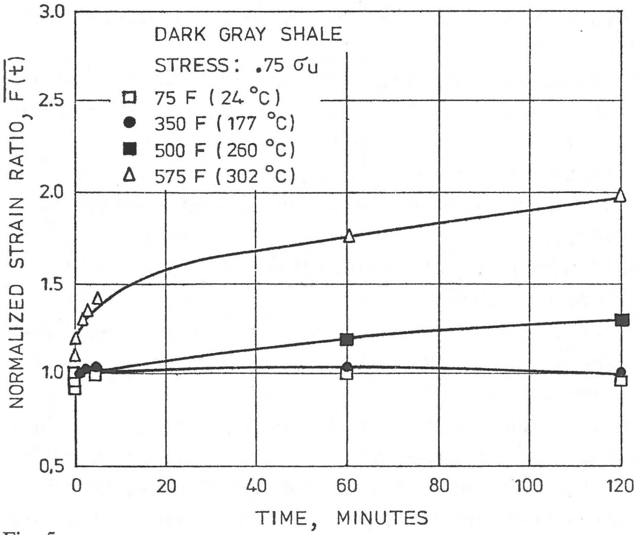

Fig. 5
Temperature dependent creep curves of dark grey shale specimens loaded in uniaxial compression normal to bedding planes at 0.75 × ultimate stress (σ_u) (Advani et al., 1976).

4. The heat conductivity coefficient (Fig. 4) decreases for sandstones (BIRCH & CLARK, 1940). This means that with increasing temperature some sort of a shielding effect counteracts a deeper penetrating temperature profile.
5. Creep increases by a factor two (as shown in Fig. 5) for shale. (ADVANI ET AL., 1976).
6. For sandstone the Poisson's ratio decreases slightly with increasing temperature. (AKTAN & FAROUQ ALI, 1975).

CAVITY STABILITY

Before a field project for underground coal gasification is started the stability of the cavities during gasification should be known. A finite element computer programme has been used to arrive at some preliminary answers. The programme ICES-STRUDL (KOK, 1981; KOK & VRIJMAN, 1980) operates with a linear elastic model. The influence on the principal stresses has been calculated. As measurements on Dutch Carboniferous rock are not available the values of the rock mechanical parameters have been assumed.

The finite element model in Fig. 6 represents a horizontal borehole leading to the reaction chamber and just outside the coal layer. The behaviour of the cavity is symmetrical around the vertical axis through the cavity. Roof and floor rock are not likely to be the same and therefore a horizontal symmetry has not been used. The elastic modulus, Poisson's ratio, overburden stress, horizontal stress and thermal expansion coefficient for sandstone that are used in the calculation are given in the legend of Fig. 6. Creating the cavity increases the major principal stress around the cavity by about a factor of two. An infinitely long cavity being kept at a temperature of 1000° C for a certain time results in a temperature profile into the rock as shown in Fig. 9. With increasing time the temperature will penetrate deeper into the rock. After 0.5 day

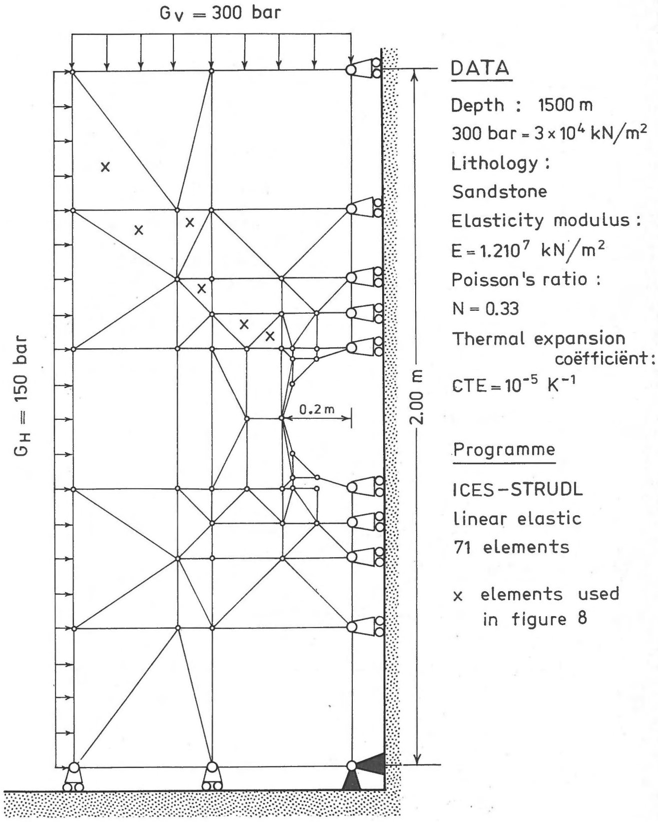

Fig. 6
Borehole model finite element method.

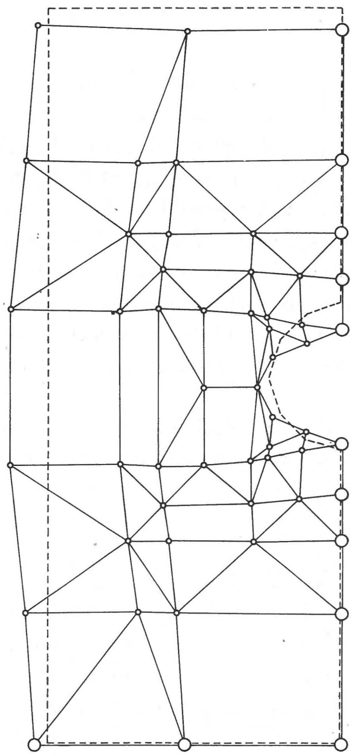

Fig. 7
Deformation exaggerated as a result of overburden pressure and 0,5 day temperature gradient.

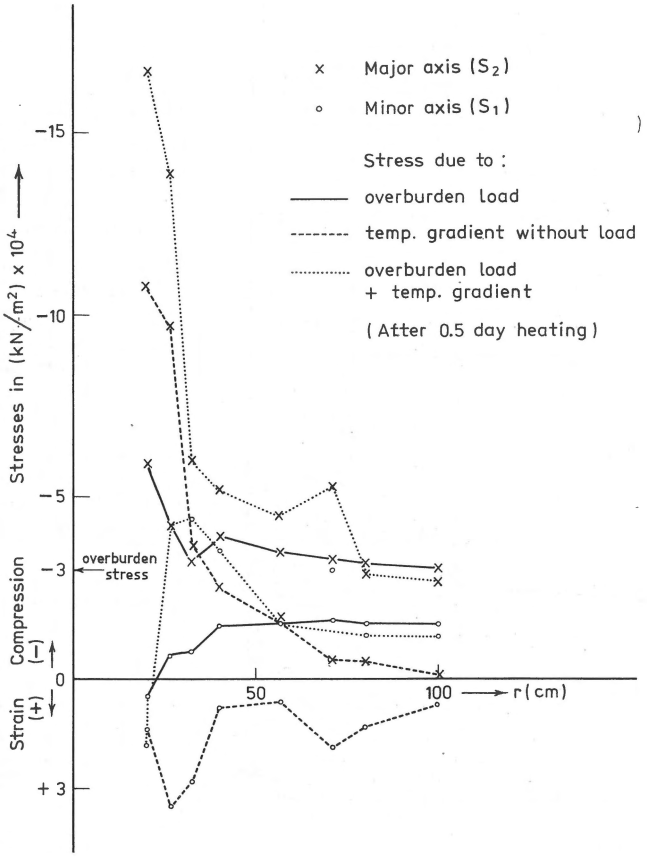

Fig. 8
Major and minor principle stresses versus the distance from the centre of the borehole.

the temperature gradient causes the stress in the sandstone rock near the borehole to increase the major stress three to four times the original overburden stress (Fig. 8). The effects of the thermal stresses and the cavity increase the major principal stress by a factor six compared to the overburden stress of 300 bar at 1500 m (Fig. 8). The deformation of the borehole and country rock under these conditions is shown in Fig. 7. The deformation is the result of linear elastic behaviour. Stability criteria are not taken into account at this stage of the investigation, as no measurements are available.

A reaction chamber can be simulated by introducing a different geometry, by a coal layer and different roof and floor rocks in the finite element programme.

FUTURE RESEARCH

In this paper assumptions for the rock properties have been made to allow simulation of the behaviour of the rock surrounding the cavity. The rock mechanical properties are temperature dependent. It is therefore necessary to measure the properties of Dutch Carboniferous rocks at temperatures up to 1000° C to simulate the behaviour of the rock surrounding the cavity with a suitable finite element programme more accurately. The research programme intended for the next three years is as follows:

- Construction of a triaxial pressure cell able to measure a stress/strain curve of sedimentary rocks representative of bedrock conditions for temperatures up to 1000° C.
- Obtaining Carboniferous rock samples comparable to the Dutch Carboniferous via German coal mines on the Dutch border.
- Mineralogical evaluation of these rocks before and after heating to 1000° C.
- Interpretation of the measurements of the triaxial rock properties so that they can be used in a computer programme.
- Application of the measured rock properties in a finite element programme operating with a visco-elastic model. For each gasification stage a temperature profile will be calculated and the rock properties appropriate to the temperature profile will be assigned to the elements. The measurements will permit the introduction of stabily criteria into the computer programme.

CONCLUSIONS

1. The high temperature in the gasification chamber causes considerable thermal stresses which could make the cavity unstable and thereby disturb the gasification process.
2. A review of the literature indicates that the mechanical properties of rock are temperature dependent so that with increasing temperature, (a) the elastic modulus decreases, (b) the ultimate strength decreases, (c) the ductility increases, and (d) the heat conductivity coefficient decreases. The elastic modulus, is in general permanently lowered after cooling down. Poisson's ratio and the thermal expansion coefficient change little with temperature.
3. To predict the behaviour of the country rock in field tests the finite element method must be applied to simulate field

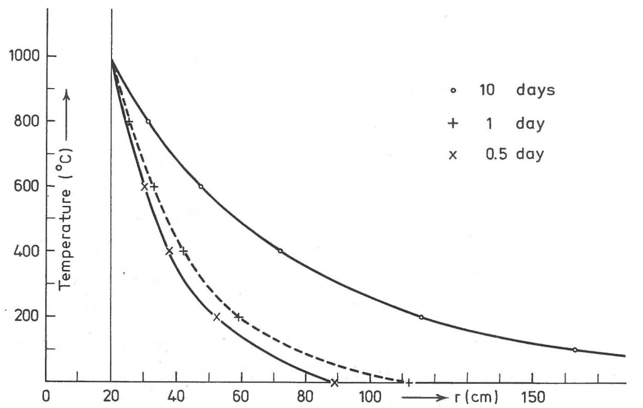

Fig. 9
Temperature profile for a cylinder with a radius of 20 cm with zero initial temperature and a constant surface temperature of 1000° C (Carslaw & Jaeger, 1959).

conditions with different lithologies and temperature profiles, so that the rock properties of each element can be established.

REFERENCES

Advani, S.H., L.Z. Shuck & Y.T. Lin 1976 Thermo-visco elastic considerations associated with underground coal – Proc. 2nd Annual Underground Coal Gasification Symp. (Morgantown, U.S.A.) 10-12 Aug. 1976, Merc/SP-76/3: 266-271.

Advani, S.H. & F.D. Gmeindl 1979 Structural and fracture mechanics simulations associated with in situ gasification of bituminous coals – Proc. 5th Underground Coal Conversion Symp. (Alexandria, U.S.A.) 18th June 1979, Conf-790630: 331-341.

Aktan, T. & S.M. Farouq Ali 1975 Effect of cyclic and in situ heating on the absolute permeabilities, elastic constants and electrical resistivities of rocks – SPE-AIME Pap. 5633.

—— 1978 Finite element analysis of temperature and thermal stresses induced by hot water injection – SPEJ 18: (6) 457-471.

Birch, F. & H. Clark 1940 The thermal conductivity of rocks and its dependence upon temperature and composition. Am. J. Sci. 238: 529-558.

Carslaw, H.S. & J.C. Jaeger 1959 Conduction of heat in solids – Oxford University Press (London): 510 pp.

Clark jr., S.P. 1965 Handbook of physical constants – Geol. Soc. Am. (New York): Mem. 97.

Grupping, A.W. 1978 Ondergrondse steenkoolvergassing met behulp van zandvulling – De Ingenieur 90: 541-548.

Grupping, A.W. & R. Pieterson 1981 Underground coal gasification in thin dipping seams – Proc. 7th underground coal conversion symp. (Fallen Leaf Lake, California) 168-180.

Heard, H.C. 1960 Transition from brittle fracture to ductile flow in Solnhofen Limestone as a function of temperature, confining pressure and interstitial fluid pressure – Geol. Soc. Am. Mem. 79: 193-226.

Ketting, J. 1981 Het mechanisch gedrag van gesteente rondom een ondergronds vergassingskanaal – Thesis T.H., Delft: 67 pp.

Kok, A.W.M. & C.F. Vrijman 1980 ICES-STRUDL, deel 2, continue constructies met de elementen methode – T.H. Delft, Afdeling der Civiele Techniek. Intern. Rapp. 67 pp.

Kok A.W.M. 1981 A theoretical manual for STRUDL – European ICES Distribution Agency, Eurocopi, J.R.C., Euratom: 191 pp.