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Dedicated to Professor Dr.-Ing. E. Bahke on his 65th birthday

Assessment of Methanol as a Carrier Liquid for Coal Transport Through Pipelines

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Summary

The use of pipelines for the transportation of coal in slurry form has great advantages over more conventional means of transport. At present water is usually used as a carrying medium but this has some disadvantages. The author reviews the possible use of methanol as an alternative and discusses at length the pertinent economic and technological factors involved.

1. Introduction

The continually rising price of oil and the realization that oil reserves are limited have led to a resurgence of coal in the industrialized nations. For coal to play an important role in the future, new processes must be developed to adapt this source of energy to the needs of domestic and industrial consumers and to take into account environmental considerations. In addition, large quantities of coal, or energy produced from coal, must be transported at economical conditions from the coal fields over considerable distances to the main centres of consumption. The present capacity of conventional overland and marine transport facilities (railways, ships and ports of transshipment) would not be sufficient to meet the increasing demands for coal transportation. Considerable efforts are therefore being made throughout the world to develop means of converting coal into consumer-oriented gaseous or liquid fuels which can be transported economically through pipelines, much in the same way as gas or oil. The advantages of pipeline technology have already been realised in transporting slurries of fine ground coal and water on a commercial scale. The hydraulic transport of coal has proved to be as economical as pipeline transportation of other raw materials such as iron ore, phosphates and limestone. Nevertheless, coal-water pipelines have some disadvantages. Firstly, water has no fuel value and is therefore mere ballast, secondly, the pipeline must be buried as a protection against frost, and in addition, the coal must be dewatered after transportation, a process which involves considerable cost. In an article on "Alternative Carrying Media and Agglomeration Processes for Transportation of Coal" [1], the use of oil, methanol, ethanol, LNG and CO_2 as alternatives to water for the pipeline transportation of coal have already been discussed. None of these alternatives has yet been used on a commercial scale, although it is generally recognized that methanol (CH_3OH) is most likely to be used.

One of the major advantages of methanol is that it can be produced from the coal itself via the processes of gasification and methanol synthesis. Furthermore, methanol is not mere ballast like water, but a source of energy, which is clean and can be easily transported.

After transportation, coal-methanol slurry can be used directly to fire power stations. There are various other possibilities; after separation, the methanol can be used to fire power stations during periods of high demand or as a chemical feedstock. Finally, the methanol can be returned to the head station of the pipeline and reused for transportation. As methanol has a low freezing point, the pipeline need not be buried.

Studies have therefore been undertaken concerning the suitability of methanol as a carrying medium for the pipeline transportation of coal.

2. Chemical and Physical Properties of Methanol; Safety Aspects

Methanol is a colourless flammable liquid with a mildly alcoholic, slightly pungent characteristic odour. The methanol molecule (CH_3OH) consists of an OH group and a methyl radical; its chemical properties are therefore more similar to those of water than to those of hydrocarbons. In contrast to benzine, the methanol molecule has only one carbon atom (C) and therefore does not have a C-C-carbon bond. In addition, methanol has one oxygen atom (O) and therefore belongs to the group of oxygeneous fuels.

Table 1 shows the main properties of methanol.

At 60 °C, methanol has the same kinematic viscosity as water (0.45 cSt); between 60 °C and 0 °C the kinematic viscosity of water is greater than that of methanol. The kinematic viscosity of methanol increases progressively from its boiling point (65 °C) to its freezing point (—98 °C).

Methanol has a higher heating value of 22.46 MJ/kg and a lower heating value of 19.67 MJ/kg.

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Table 1: Properties of Methanol (CH_3OH)

Boiling Point	65°C	Flash Point	11°C
Melting point:	—98°C	Flammability limits (% by volume) Upper Lower	 26.5 % 5.5 %
Density at 0°C:	0.81 g/cm^3	Self-Ignition temperature:	450°C
Appearance: Colourless liquid; odour similar to that of diluted shellac			
Miscibility: Completely miscible with water in all proportions			
Explosion Hazards: When mixed with air or water			
Health Hazards: Both as liquid and vapour, has toxic effects on central nervous system, optical nerves, kidneys, liver, heart and other organs.			
Symptoms: Intoxication, dizziness, headaches, nausea, fainting, impairment of vision, unconsciousness, respiratory arrest.			
Threshold for Olfactory perception: 5 ppm			

Because of its toxicity and the explosion hazards it presents, methanol must be handled with great care; however, expert opinion is that a coal-methanol slurry pipeline would be no more hazardous than oil or product pipelines.

3. The Preparation and Use of Methanol; Cost Considerations

The preparation of methanol always involves the hydration of carbon monoxide and carbon dioxide according to the following equations:

$$CO + 2H_2 \leftarrow \rightarrow CH_3OH$$

$$CO_2 + 3H_2 \leftarrow \rightarrow CH_3OH + H_2O$$

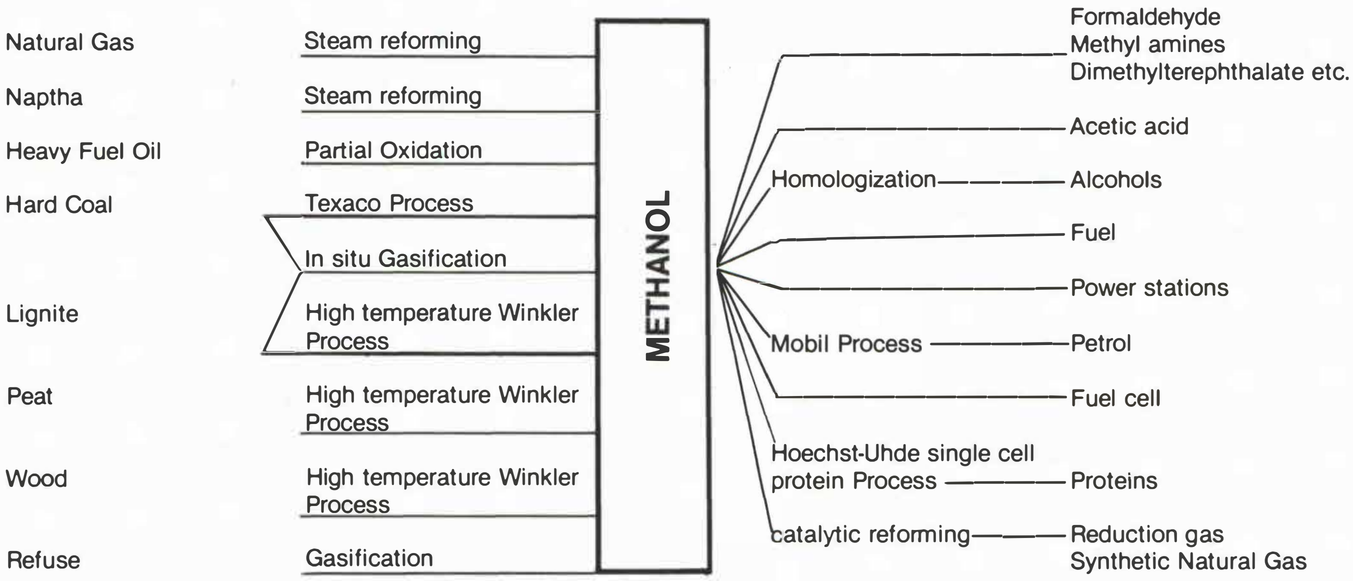
To date, methanol has mainly been produced from natural gas, although heavy fuel oil has also been used. Fig. 1 shows the feedstocks and methods used to produce methanol and its various applications and end products [2]. In view of the potential applications and the importance of methanol as a source of energy and as a carrying medium for the pipeline transportation of coal, coal will probably increasingly be used as a feedstock for methanol synthesis in the future.

In the light of the current discussion of alternative and renewable sources of energy, biomass and refuse also deserve consideration as raw materials for methanol synthesis.

As yet, the main application of methanol has been as a chemical feedstock, but interest has now focussed on the use of methanol as an alternative or an additive to automotive fuels, i.e., as secondary energy for the transportation sector. Huge methanol synthesis plants would, however, be required even if only 15 % methanol was added to motor vehicle fuels.

World methanol production is currently some 14 million tonnes per annum. Because of the new applications for methanol which are currently under consideration, it is expected that production capacity may increase as much as tenfold within the next ten to fifteen years. The increase may be even greater if the use of methanol for the pipeline transportation of coal proves to be technically and economically viable.

Fig. 1 Productions and applications of methanol



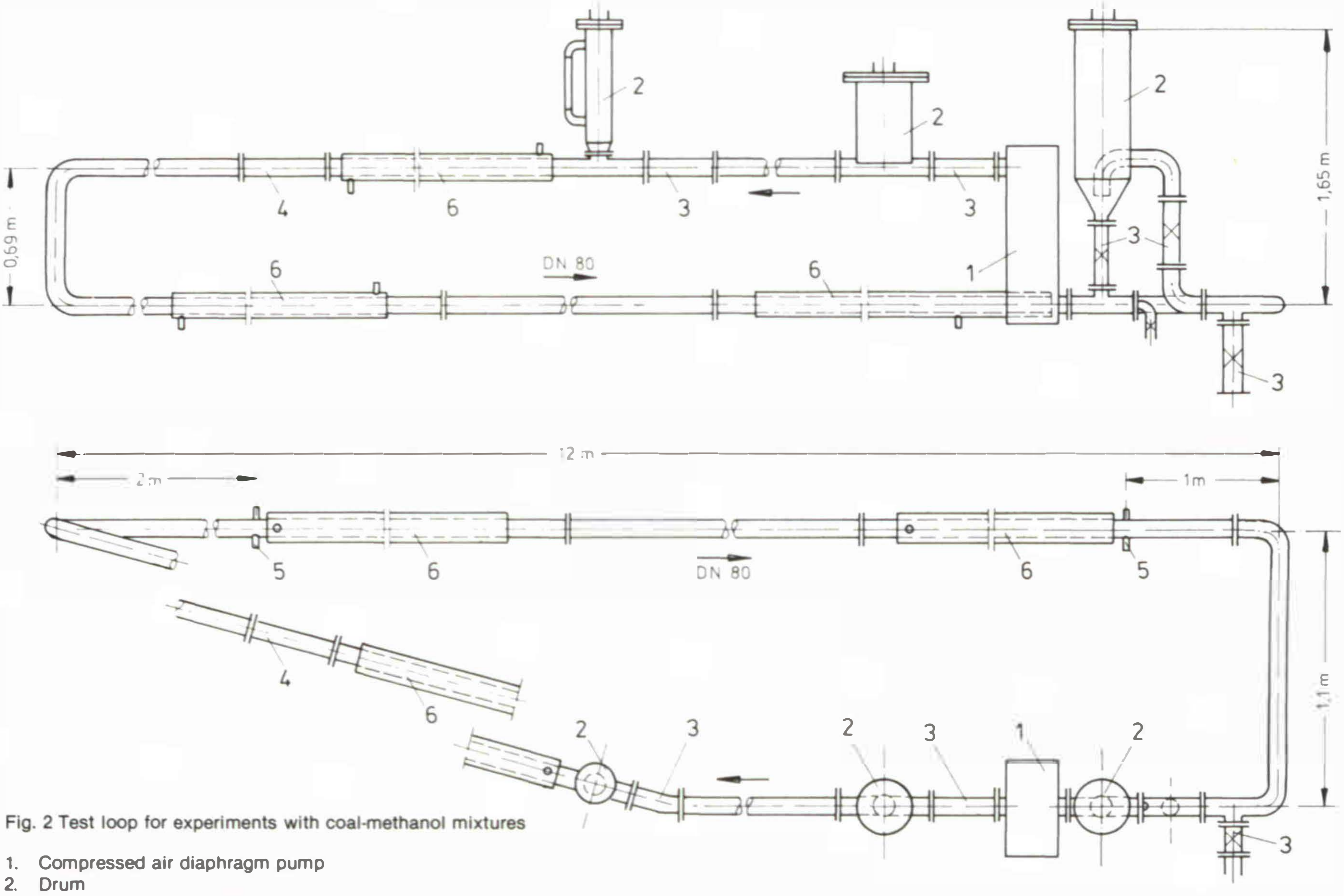


Fig. 2 Test loop for experiments with coal-methanol mixtures

1. Compressed air diaphragm pump
2. Drum
3. Pinch valve/compensator
4. Transparent inspection run
5. Pressure taps
6. Heat exchanger

According to [2] production costs of methanol based on mid-1980 West German raw material prices are as follows:

- Methanol produced from lignite (DM 17 per tonne): approx. DM 265 per tonne
- Methanol produced from hard coal (DM 170 per tonne): approx. DM 490 per tonne
- Methanol produced from natural gas (DM 6/GJ): approx. DM 290 per tonne
- Methanol produced from heavy fuel oil (DM 280 per tonne): approx. DM 380 per tonne

Taking into account an increase of 30% in the price of natural gas and an increase in the price of heavy fuel oil to DM 350 per tonne, production costs for methanol produced from these two raw materials would be DM 350 per tonne and DM 455 per tonne, respectively.

In the Federal Republic of Germany, methanol can be produced most economically from lignite, followed by natural gas and heavy fuel oil; hard coal is not competitive as a feedstock. Depending on price levels, hard coal could be competitive in other countries. If hard coal prices were of the order of DM 60 to 70 per tonne, production costs of methanol from hard coal would be DM 290 to DM 310 per tonne.

In 1981, the average price of methanol in the Federal Republic of Germany amounted to approx. DM 460 per tonne fluctuating between DM 270 and DM 600 per tonne as a function of plant size. Under these conditions methanol could be used economically as a source of energy if it were produced in sufficiently large plants.

4. Laboratory and Test Loop Tests With Coal/Methanol Mixtures

The test loop had to be designed to take into account the properties of methanol. The loop (Fig. 2) was constructed as a completely closed circuit of DN 80 pipes with a double-acting compressed air diaphragm pump (1). An axial or centrifugal pump was not used as this would have required liquid seals. Drums (2) were installed to compensate the volume and pressure fluctuation caused by the pump; these were half filled with nitrogen to prevent the formation of an explosive oxygen-methanol mixture. In order to prevent air from entering the system during filling operations, the coal bin (2) located at the suction site of the pump was pressurized with nitrogen and coal was filled in through an inlet in the cover of the bin.

Heat exchangers (6) consisting of DN 125 casings with water flowing through the annular space were installed to keep the system at a constant temperature.

The throughput was regulated by means of a pressure control valve located in the compressed air line to the diaphragm pump. Compensators (3) were installed to minimize vibrations introduced into the system from the pump. Events inside the line could be observed through an observation run (4), consisting of a transparent perspex pipe section. Pressure measurements were taken at pressure taps (5) using piezoelectric crystals.

Table 2: Data of the High Volatile Coal used for the Tests (from the Monopol Mine)

Lot	1		2		3	
Particle Size mm	by mass %	Ash content (dry) %	by mass %	Ash content (dry) %	by mass %	Ash content (dry) %
3.15	11.12	27.85	—	—	—	—
3.15 to 2.0	23.09	26.13	—	—	—	—
2.0 to 1.0	28.90	26.81	—	—	0.09	3.53
1.0 to 0.8	8.65	33.04	—	—	0.65	3.53
0.8 to 0.5	11.68	39.85	0.77	6.67	9.12	3.59
0.5 to 0.315	7.20	40.81	2.69	5.86	26.07	3.34
0.315 to 0.125	5.86	48.27	17.66	3.75	43.03	3.85
0.125 to 0.063	1.30	57.50	21.00	4.81	7.91	9.53
0.063 to 0.045	0.28	52.04	8.71	6.93	1.86	12.96
< 0.045	1.92	68.79	49.17	16.78	11.27	29.05
Volatiles (dry + ash free) by mass	37.28 %		35.43 %		34.21 %	
Mass	227 kg		215 kg		225 kg	

The experiments on the test loop were intended to determine pressure losses during transportation as a function of particle size and coal concentration in the slurry. Two types of coal were used for the tests:

- Dried high-volatile coal (density 1.33 g/cm³, particle size variable, but as small as possible (cf. Table 2)).
- Dried or non-dried lignite (density 1.16 g/cm³, mean particle size 1.6 mm)

The exact reproduction of the particle size distribution of the coal transported in the Black Mesa Coal Pipeline, USA, proved to be impracticable. With regard to practical applications, it also seemed unrealistic to prepare large quantities of very small particle sizes (< 20 μm) as recommended in American publications. For this reason, high-volatile coal with random particle sizes from the Monopol mine as small as could be obtained from normal screening process was used for the tests. Tests were carried out using both methanol and, for comparison purposes, water as carrier media, under the same experimental conditions.

Because of the hygroscopic properties of methanol, water is absorbed from coal thus producing a water-methanol carrier liquid; as it is not possible to dry coal completely in practice, tests were also carried out using coal-methanol-water mixtures in varying concentrations to simulate actual operating conditions.

Prior to the test loop work, preliminary tests were carried out in the laboratory; the main results were as follows:

- Coarse coal (mean particle size 130 μm or 500 μm) and even fine particles (with a mean size down to 20 μm) precipitate relatively quickly and can easily be separated from methanol by filtration.
- Fine particles (mean size less than 20 μm) form a relatively stable suspension with methanol.
- The properties of hard coal are not changed by exposure to methanol under simulated operating conditions (simulated by 120 hours at 60 bar in an autoclave agitator).
- The swelling properties of coking coal are not changed by exposure to methanol.
- Methanol does not react with lignite or hard coal. Lignite from the Fortuna Nord mine, 60 % and 10 % moisture content, and high-volatile coal from the Monopol mine were used for the tests. In the lignite tests, less than 0.5 % of organic matter was found in the methanol phase of the suspension; in six-day experiments at 20—25 °C using hard coal, the methanol phase of the methanol-hard coal suspension contained only 0.4 % of low molecular weight organic impurities.
- Lignite swells in methanol, forming a paste; this process is even more marked at temperatures in excess of 50 °C, with the result that viscosity increases sharply.
- Accelerated corrosion takes place in the presence of water.

The test loop tests showed that pressure losses occurring during the transportation of pure methanol were lower than those for pure water. This may be explained by the lower surface tension, density (0.81 g/cm³ at 0 °C) and viscosity of methanol at normal temperatures, as compared to water.

Tests with suspensions of coarse coal (lot 1) in methanol resulted in pressure losses which were almost always higher than those for pure water and coal-water slurries. Pressure losses for a coal-water slurry containing approximately 30 % coal by volume were approximately equal to those for a coal-methanol slurry containing 20 % coal by volume (Fig. 3).

The highest pressure losses were obtained for slurries consisting of pure methanol and large volumetric concentrations of coal. Tests with the same coal in suspension with methanol and water gave pressure losses for a coal content of 40 % by volume equal to those for a water-coal slurry containing 20—30 % coal by volume.

In the course of the tests it became clear that pressure losses for a constant 40 % by volume suspension of coal in methanol decreased as the tests progressed (Fig. 4). This phenomenon is explained by reduction in the particle size of the coal due to exposure to methanol.

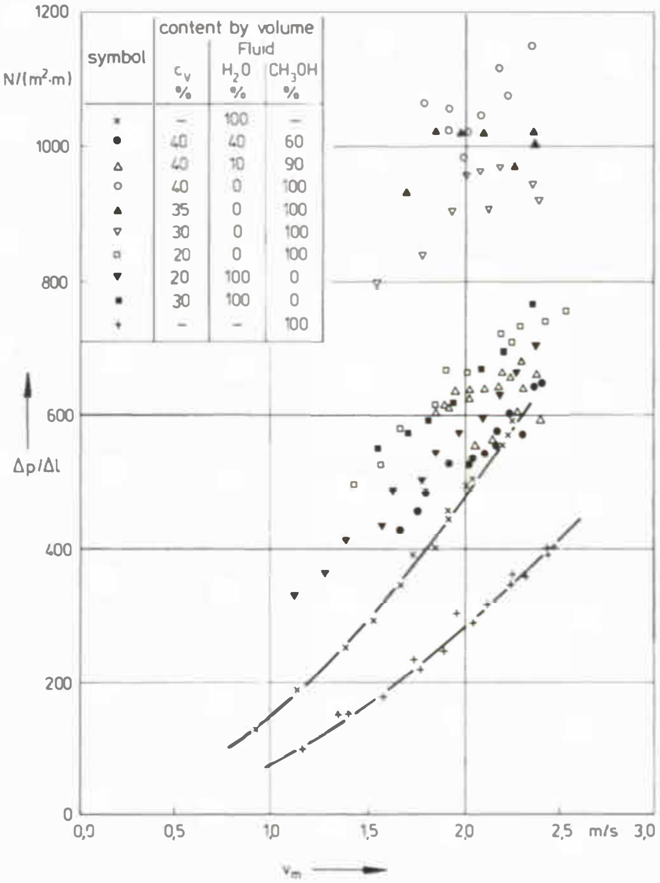


Fig. 3: Pressure gradient $\Delta p/\Delta l$ as a function of velocity v_m for coal-water, coal-methanol and coal-water-methanol mixtures transporting coarse coal (lot 1)
c_v = % coal by volume

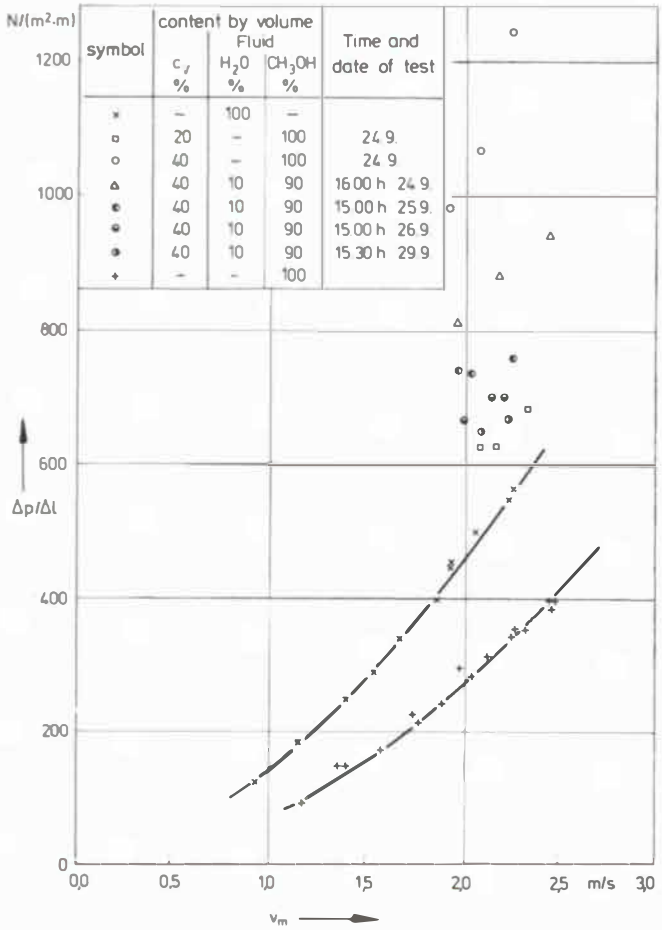


Fig. 4: Pressure gradient $\Delta p/\Delta l$ as a function of velocity v_m for coal-methanol and coal-water-methanol mixtures transporting coarse coal (lot 1) after various times in suspension.
c_v = % coal by volume

Pressure losses for suspensions of medium grained coal (lot 3) in methanol and methanol-water mixtures were between those for pure water and pure methanol (Fig. 5). The pressure gradient for a suspension of this type of coal in water closely approximated that of pure water and has not been shown for the sake of clarity. Finally, the suspension of the finest coal used for this test (lot 2) in methanol showed the characteristic behaviour of homogeneous suspensions (Fig. 6).

During the tests with lignite, there were initial problems with starting the pump, because it proved difficult to force the lignite sediment back into suspension. The behaviour of the lignite-methanol suspension was similar to that of homogeneous suspensions, where slurry pressure loss curves deviate from those recorded for the pure liquid, and critical velocities are very low (Fig. 7).

5. Theory and Practice

The results of tests using water as a carrying medium showed good agreement with the theoretical values predicted. The methanol tests only showed good agreement for suspensions with low coal contents. As mean particle size and coal content increased, pressure loss fell increasingly short of the values predicted. Adapting the theoretical predictions to the test results, this phenomenon must be due to a progressive reduction in particle size due to the swelling and disintegration of coal particles in methanol, a hypothesis supported by the long term tests with Lot 1 coal and the laboratory tests with lignite. Disregarding this phenomenon, Fig. 8 shows that, for a pipeline with an outer diameter of 457.2 mm and a wall thickness of 8.6 mm, the minimum pressure loss for methanol-coal mixtures occurs at considerably higher pressure losses and considerably higher velocities than for water-coal slurry with the same coal content and properties. The behaviour of coal-methanol slurries approaches that of coal-water slurries if the particle size of the coal suspended in methanol is approximately half that of the coal suspended in water. The pressure gradient for both types of slurries then reaches nearly the same optimum value at approximately the same, moderate velocity.

The theory for calculating the pressure loss is therefore valid for methanol-coal slurries if calculations are based on effective particle size. The optimum particle size for coal to be transported in methanol is 100—300 μm; together with the finest particles these particles then form a stable suspension of the pseudohomogeneous type.

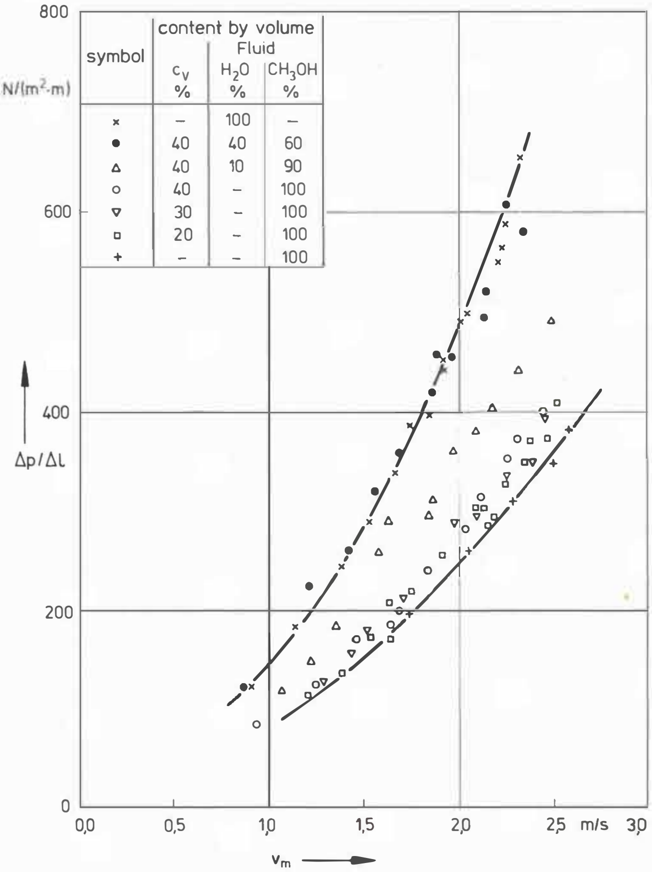


Fig. 5: Pressure gradient $\Delta p/\Delta l$ as a function of velocity v_m for coal-methanol and coal-water-methanol mixtures transporting medium-grained coal (lot 3)
c_v = % coal by volume

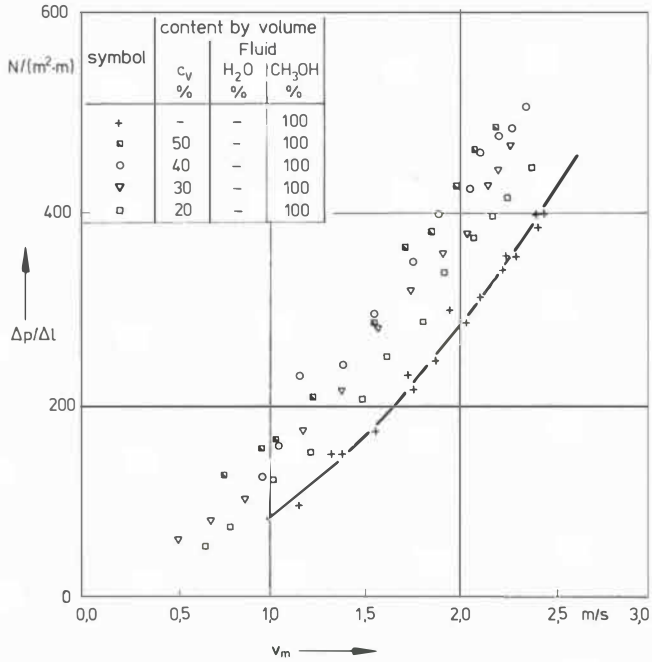


Fig. 6: Pressure gradient $\Delta p/\Delta l$ as a function of velocity v_m for coal-methanol mixtures transporting fine coal (lot 2)
c_v = % coal by volume

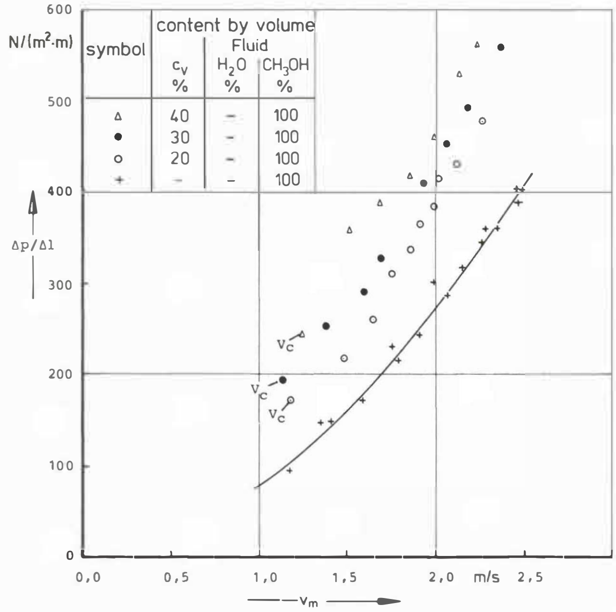


Fig. 7: Pressure gradient $\Delta p/\Delta l$ as a function of velocity v_m for lignite-methanol mixtures
c_v = % lignite by volume

6. Viability

A comparison of the cost of coal-methanol pipeline transportation with different modes of energy transportation, such as coal transportation by rail, coal-water pipelines, barges and power lines on the basis of 1981 prices shows that the cost per kilowatt/hour of energy transported is lowest for coal-methanol pipelines [3].

This result is due to the inherent advantages of pipeline transportation and the fact that methanol is itself a source of energy.

7. Prospects

The tests have shown that the pipeline transportation of coal-methanol suspensions is technically feasible and has certain advantages if coal with particle sizes of about 100 μm is transported. Coarser coal can also be transported but the particles then disintegrate during transport. Because of the hazards presented by methanol, the whole design of a pipeline system for the transportation of methanol-coal slurry, particularly the head station and terminal, would have to be different from that of a coal-water pipeline. For example, certain components would have to be sealed off.

As the freezing point of methanol is very low, methanol pipeline systems could be used for the rich coal fields of Alaska, Canada and Russia which are located in permafrost areas, i.e., regions, where all the advantages of such a system can be utilized. The energy required for transportation could be taken from the medium itself.

The quantity of methanol required for a large modern pipeline would, however, exceed the capacity of the largest methanol plants currently available. On the other hand, methanol demand is still relatively low. As the cost of methanol is relatively high, it would probably be uneconomical to fire a coal-methanol mixture in power stations. The coal and the methanol would have to be separated and the methanol either pumped back to the head station or used as a chemical feedstock.

In the short term, coal-methanol pipelines will therefore probably only be used in exceptional cases, if methanol demand is not drastically increased, for example by laws encouraging the use of methanol as an automotive fuel. Such developments could be accelerated if dependence on oil producing countries reaches an intolerable level.

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Fig. 8: Theoretical pressure gradient curve for the hydraulic transportation of coal in water and in methanol in a pipeline with an outer diameter of 457.2 mm and a wall thickness of 8.6 mm. $\Delta p/\Delta l$ = pressure gradient; v_m = velocity; w = percentage coal by mass and c_v = percentage coal by volume. Curves 1 to 3 were calculated on the basis of a mean particle size of 0.3 mm. Curve 4 was calculated on the basis of a reduced mean particle size of 0.17 mm.