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PIPELINE TRANSPORT OF FOSSILE FUELS

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Summary : *The paper deals with hydraulic pipeline transport of fossil fuels. A general analysis of coal and heavy viscous oil pipelining systems is introduced and pipeline transport of concentrated coal-water slurry, coal-water fuel, coal pipelining in other than water carrier liquid (e.g. methanol) and capsule pipeline transport (coal-log pipelining) is described.*

1. Introduction

With annually increasing volumes of various materials to be handled and/or transported an interest arises for the new economical and operationally safe kinds of transport, including the pipeline one. Our preliminary investigation has shown that application of a special kind of pipeline installations can be very useful for solving the problem. According to our opinion and experiences, the hydraulic, pneumatic and capsules pipeline transport systems may be successfully used to solve this task. Of course, the state of knowledge in the field of pipeline transport requires applying also experimental research beside a numerical calculation for the design of special transport installations.

The pipeline transport in comparison with the conventional one has several expressive advantages, especially in highly populated industrial areas. It can be fully mechanised and automated, it needs very low human activity in the direct contact with transported products, it can be completely closed with a very small contact with environment. It can transport a large quantity of material and has only negligible demands for space. It should simultaneously ensure high operational efficiency, safety and reduction of total costs of transport.

For successful and economical exploitation and utilisation of isolated sources of different raw materials including fossil fuel, located in remote and/or hardly accessible regions, the problem of operationally safe and economically acceptable way of transport becomes usually one of the decisive parameters.

The pipeline transport seems to be one of the promising and powerful systems which can serve for the transport of coal or another fossil fuel on long distances, from dozens to thousands kilometres and can compete with the conventional railway and barges transport.

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Because of the limited sources of oil and natural gas a considerable development and progress in the coal pipelining can be expected especially in USA, in the former Soviet Union and also in other countries in a near future.

2. Analysis

The world-wide knowledge in design, construction and operation of hydraulic pipeline systems based on experimental investigation and operational experiences as well as on theoretical calculations has shown the efficiency and prospect of the pipeline transport of coal in comparison with other kinds of transport. However, at a level of technical projects a series of weaknesses and/or imperfections in contemporary used systems of the coal pipelining with water used as a carrier liquid have detected. A rather difficult, energy consuming and expensive process of dehydration of coal slurry before combustion is one of them. Besides, transport of a great quantity of „ballast“ - the carrier water - also requires considerable power inputs and usually also expensive water treatment before reutilization or discharging the water into the natural streams. In addition, water is at present very valuable and hardly available medium.

Because of permanently problematic supply of natural oil and gas, often in consequence with economical and political pressure, the present time brings a new interest to solve the problem of optimisation of pipeline transport of coal. We could pick out three main directions of modern long distance coal pipelining.

The first way is *pipeline transport of concentrated coal-water slurry*. It assumes that utilisation of coal particle distribution preparation and/or using of various additives can substantially increase weight concentration of coal-water slurry till 70-80 %. For example, Black Messa Pipeline realised in USA transports 4.8 million tons of coal per year over the distance 439 km from the colliery in North Arizona to power plant Mohave near the border of Nevada and California with weight ratio of coal to water about 1 : 1, without using any additives, Vlasak & Buchtelova (1976). Recently, in the USA, Italy, China, Russia and other countries several coal pipelines were already realised.

Even substantially smaller content of water in slurry could be reached - approximately 75 % of coal and 25 % of water due to using the special additives - fluidising and stabilising agents. The high concentration chemically stabilised coal-water slurry with optimised grain size distribution - called coal-water-fuel behaves as homogeneous fluid. It is transportable over long distances and stable. There are no limitation concerning the critical velocity or critical hydraulic gradient. Another advantage is the possibility of long time storage without solid-liquid phase separation and of course no difficulties in pipeline restart. The coal-water-fuel could be directly combusted without de-watering similarly as heavy fuel oil, Ercolani (1986).

The second way is a capsule pipeline transport. Hydraulic capsule pipeline and pneumatic capsule pipeline is the transport of freight encapsulated to cylindrical or spherical bodies, so called capsules (with diameter only slightly less than the pipe), conveyed through pipeline by liquid or gas, respectively. Hodgson & Charles (1963) and Jensen (1974,1975) referred to capsule pipelining as the third generation of pipelining.

The third way of coal pipelining intensification supposes using the carrier liquid different than water. Oil products (masout, kerosene, crude oil, fuel oil and various mineral oils) or hydrocarbons (methanol, ethanol, carbonic acid, and other liquid organic compositions) can be used as a carrier liquid. Let us now deal with the possibility of coal pipeline transport in methanol.

3. Coal-methanol pipeline transport

The physical properties of the carrier liquid, especially density and viscosity, can essentially influence both main hydrodynamic parameters of the mixture flow, i.e. critical velocity V_{CR} and the hydraulic gradient I.

As an example, dependence of hydrodynamic parameters of critical regime for the sand-water mixture and sand-glycol (80 % glycol solution in water) mixture is illustrated in Fig. 1. The volume concentration C of the mixtures varied from 5 to 30 %, a mean diameter of sand was $d =$ 0.25 mm and a pipe diameter was D = 50.4 mm. The values of the critical velocity V_{CR} and critical pressure gradient I_{CR} differ substantially according to the used carrier liquid.

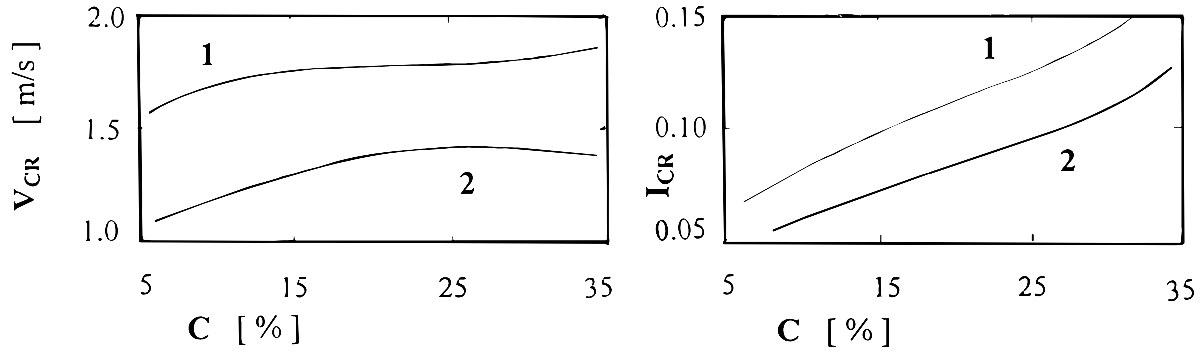

Fig.1. The effect of volume concentration C on critical velocity V_{CR} and critical hydraulic gradient I_{CR} for sand-water mixture (1) and sand-glycol solution mixture (2)

It follows from the foregoing research concerning the most effective carrier liquid for the coal hydrotransport that the majority of authors recommend to use methanol and its water solutions as a carrier liquid instead of water, Alger & Simons (1968), Snoek et al (1979), Grace (1980), Techn. Heute (1980), Wilta (1980), Aude & Chapmen (1981), Goedde (1981), Lauzon (1982). A choice of the methanol as a carrier liquid for the transport of coal is not accidental. According to Moiseev (1982) and Nekhaev (1982) the simple and fairly reliable production of methanol can put it forward in the category of the cheapest products of organic synthesis in the near future.

An annual world production of methanol increased already at present in average about 15%. The majority of methanol is now produced from petroleum or natural gas since it is about 25-50 % cheaper than production from coal. However, according to the economical prediction the difference in prices should be essentially decreased in the near future. Methanol as a carrier liquid for the coal hydrotransport offers the following scheme of the coal pipelining.

In the region of coal-mines the installation could be built where part of the yield coal could be processed on methanol and it can be used as a carrier liquid for pipeline transport of the remaining part of coal. One of the following ways of the methanol exploitation could be used at the output terminal of the transport line.

- The mixture of coal and methanol (or its water solution) can be directly burned in a boiler of the thermal power plant.
- After separation of coal and methanol the first can be used as a fuel and the second as a raw material for various purposes.
- The possibility of reutilization of methanol separated from the mixture for multiple use in the transport process should be also considered.

The using of methanol as a carrier liquid is also very advantageous due to its low temperature of freezing. It allows to lead the pipeline superficially over a ground surface even in the arctic regions what could play an important role for using the methanol for pipeline transport of coal in the northern and mountainous areas of the USA (Alaska), Canada and former Soviet Union, Goedde (1981).

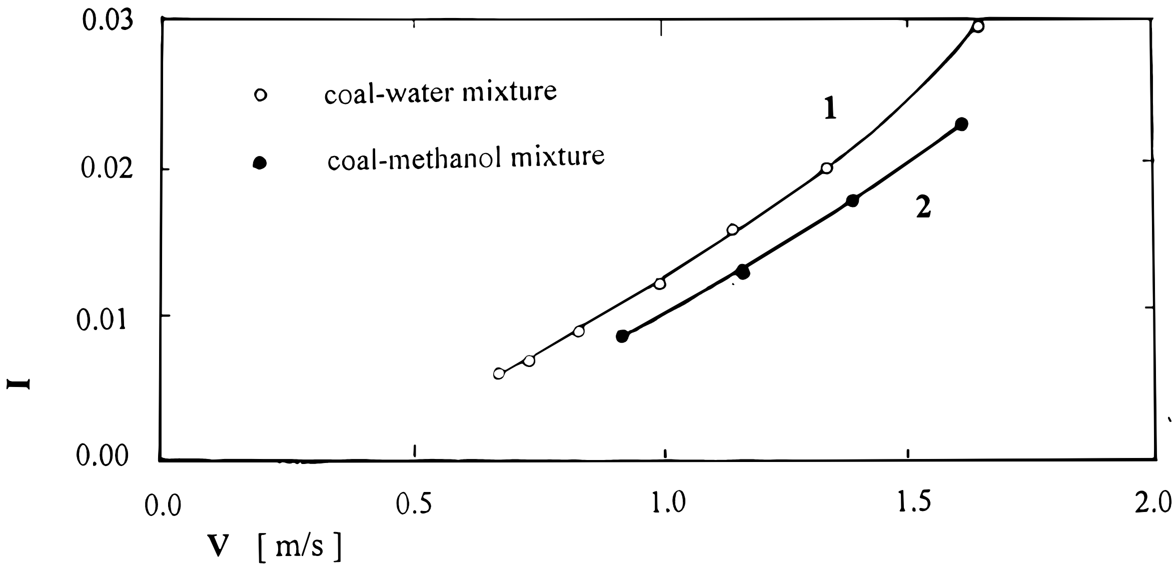

Fig. 2. Comparison of hydraulic gradient I of coal-water mixture (1) and coal-methanol mixture (2)

Based on the above mentioned, the programme of theoretical and experimental investigation of the main parameters of coal-methanol (or its water solution) mixture pipeline transport should be opened. As the first step of the programme the comparison of power consumption (dependency of hydraulic gradient I on slurry flow velocity V and solid concentration C_s) for the pipeline transport of coal-water mixture and coal-methanol solution mixture was realised. The special laboratory measurements were made to define unknown input data of semi-empirical relationships, i.e. the limit volume concentration C_m and the coefficient of mechanical friction of coal in the water or water-methanol solution k_o. The resultant comparison of the hydraulic gradient I of the coal-water and coal-methanol solution mixture flow is presented in Fig. 2, where density of coal was ρ_c = 1480 kg/m^3, diameter of the pipe was D = 0.103 mm, the maximal grain size of coal d_{max} was less than 0.25 mm, volumetric concentration C = 20 %.

The power consumption of the coal-methanol mixture is about 20 % less than that of coal-water mixture for the same value of transport velocity (except the regime close to the critical velocity V_{CR}). The reason of it is probably lower viscosity of methanol than that of the water. Similar results were also confirmed experimentally by Aude & Chapmen (1981).

However, the fundamental economical criterion of any transport system is not the power inputs, but the total transport cost per unit mass and distance. Goedde (1981) made the comparison of the total unit transport cost of the coal-methanol mixture pipelining with coal-water mixture pipelining, railway and barges transport. He pointed out that the transport of coal in methanol can be significantly profitable and competitive compare to the rest of the above-mentioned kinds of transport. Therefore, the attention should be paid to the investigation of optimal models of hydrotransport of coal-methanol mixtures.

A serious problem results from the fact that methanol is a toxic fluid (extreme permissible concentration of methanol in the air is 5 mg/m^3) and to work with it is possible only in specialised laboratories. For the pipeline laboratory research it is useful to find such substitute of methanol, which is absolutely harmless and its physical properties (density and viscosity) strictly correspond to methanol.

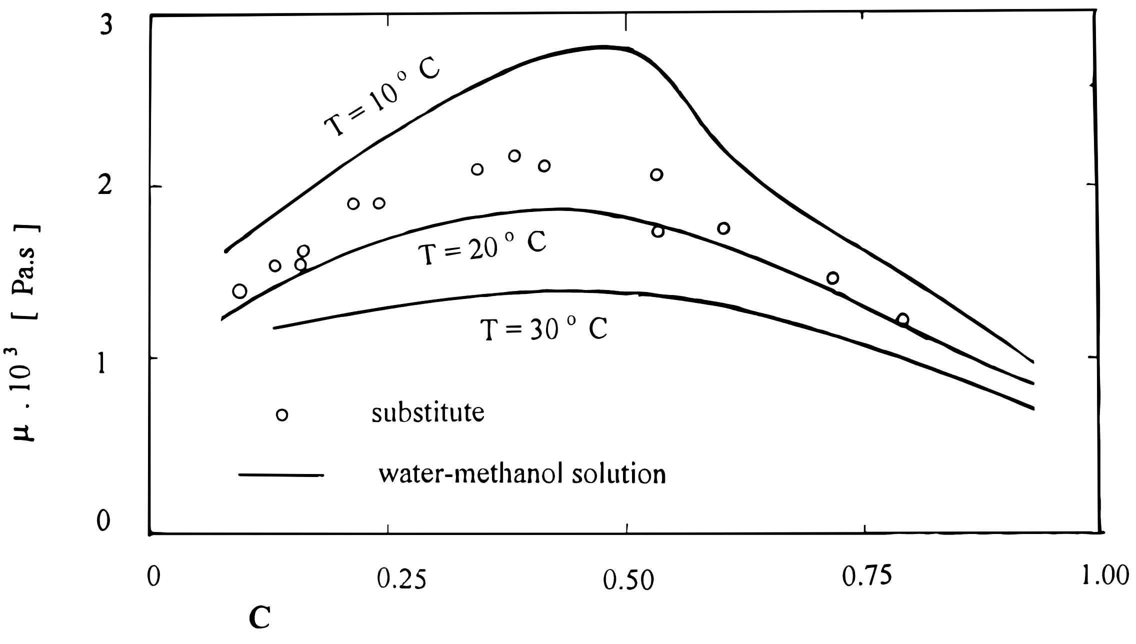

Fig. 3. Comparison of dynamic viscosity μ of a real water-methanol solution and its substitute

Based on our experiments such substitute has been found. The comparison of measured values of dynamic viscosity of the methanol solution substitute and the data available in the literature for real methanol solution are presented in Fig. 3 (the value *C* is the weight concentration of methanol in a solution). Since the measurements were realised within the temperature range T = 18-20°C, a fairly good agreement between methanol and its substitute was proved. The preliminary measurements with the substitute as carrier liquid also confirmed results illustrated in Fig. 1.

4. Coal-log pipeline transport

Capsule pipeline transport of coal, so called coal-log pipeline transport seems to be very close to commercial exploitation in the USA, Liu (1996, 2002). Coal is formed in cylindrical bodies (by using of high pressure without or with addition of some glue), which are conveyed by water in a pipe. Diameter of the body d_c is about 90 % of the transport pipe diameter *D*, length of the body L_c is about two body diameters d_c. The concentration of solids can reach a very high value (up to 80 %) and process of separation of coal and water is very easy and without additional expenses.

For carrier liquid velocity about 3 m/s capsules are conveyed in water practically without contact with the pipe wall. This flow pattern satisfies minimum power consumption and also protects the capsules and the pipe against degradation and weir. In addition, water consumption is three or fourth times less than for slurry hydrotransport and pollution of water is negligible. Using polymeric or micelle drag reducing additives could significantly decrease the power consumption what is advantageous especially for long distance pipelining, Vlasak (1995).

Coal log technology makes possible to transport up to twice more coal in the same diameter of pipe than for slurry transport and brings also another advantages compare to the slurry pipelining. Except low water and energy consumption, separation and de-watering of coal is much easier and cheaper and due to low content of water in coal the combustion process is more efficient.

It follows from economical comparison that coal-log pipeline is cheaper than truck transport for distances longer than 65 km and pipe diameter *D* = 200 mm. For *D* = 500 m even for distance over 25 km. Compare to railway, the transport cost is on the level of unit trains. For large quantity of coal it could be even less. Another advantage is given by fact that length of pipeline is usually at least about 30 % lower than that of the railway. From environmental protection point of view, capsule pipeline, similarly as slurry pipeline, is dust free, noiseless. In spite of these advantages we could expect the utilisation of coal-log pipeline system particularly for transport of coal from new mines to power station, especially in mountains area without railways and highways or in heavy populated and industrial areas, where railway is overloaded.

The most profitable application of pipeline transport is the use of a system known as a common carrier where both the transported material and carrier fluid can be transported from the same locality and are both exploited at the point of destination. Transport of crude oil and natural gas from deposits in Arctic region is very promising. One possibility can be find in transport of solidified crude oil moving as capsules in liquefied natural gas (LNG) in common pipeline, where LNG serves as the carrier liquid. The idea applying capsule pipeline technology to this case is feasible since liquefaction of natural gas is en established technology and very low solubility of crude oil in LNG was proved, Jensen (1975). Simultaneously another technical problem could be solved using this technology. Due to high viscosity of the oil considerable part of energy changes to heat and thus conventional oil pipelines can introduce serious environmental problems in the Arctic region, arising due to the relatively warmer pipeline compare to surrounding land. Heat dissipation causes melting of the surrounding permafrost with the dander for pipeline foundation, which could erode and the line can break down.

Another interesting application is transport of highly viscous oil or oil product (e.g. lubricant, asphalt) in rigid or plastic containers transported through pipe by water or low viscosity oil product. A preliminary analysis has shown substantial saving of capital cost and/or operational cost by employing the common carrier transporting system.

The comparison of hydraulic capsule pipeline transport with pipeline transport of oil products and slurry hydrotransport is particularly interesting. It was demonstrated that power consumption for transport of the same quantity of bulk cargo placed in capsules is less than in case of slurry hydrotransport, especially, for coarse-grained material of density of coal and different types of industrial wastes. As follows from Figure 4, for coarse coal transport the power consumption of slurry pipelining reaches from 300 % to 100 % higher values than that in case of hydraulic capsule pipeline transport. The energy reduction increases with reduction of the operational velocity.

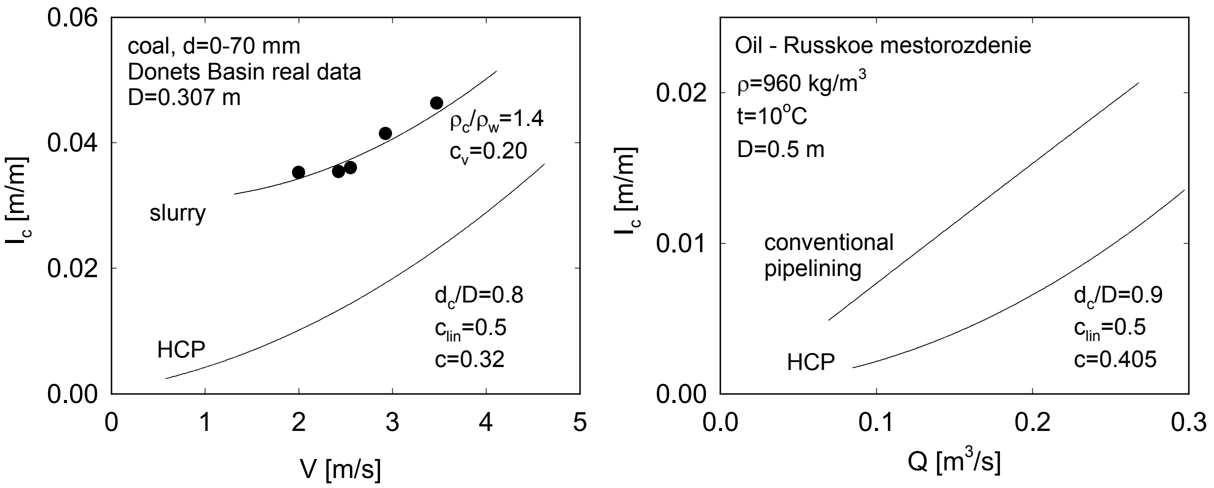

Fig. 4 Comparison of power consumption reduction for HCP and conventional transport of coal and viscous liquid

Similar result brings comparison of power consumption reduction for transport of encapsulated viscous liquid (Russian oil) conveyed by water with conventional pipeline transport of the oil. Transport of viscous oil and oil products by means of capsule pipelining may again provide power consumption reduction from 50% to 70%, the reduction increases with operational velocity. Since for low temperature the oil viscosity significantly increases, hydraulic capsule pipeline transport of highly viscous oil and oil products for long distances in arctic conditions can be economically very interesting. Capsule pipeline transport could be recommended as suitable transport especially for longer distances when power consumption becomes the most important for operational cost.

5. Conclusions

The conveying of coal by fluids through the pipeline has been proposed as a potential method of bulk transport.

Except traditional slurry transport of coal as coal-water slurry or coal-water fuel, pipeline transport of coal in hydrocarbons (e.g. methanol) seems to bring some advantage especially for arctic areas.

Very promising, especially for long distances, is coal-log pipeline technology, which brings significant saving of energy and water consumption, increasing of combustion efficiency and decreasing of transported material degradation and pipe wear.

Although enough is known about the hydrodynamics of slurry and capsule pipeline transport to design and to construct a pilot plant or even commercial pipeline for transport of coal or other energetic materials, the additional research should be done for safe and economical operation for each individual pipeline.

6. Acknowledgements

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