SOME POSSIBLE PROBLEMS WITH PIPELINES IN PERMAFROST REGIONS[1]

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The discovery of a major oilfield at Prudhoe Bay on the north coast of Alaska and the potential existence of similar large fields in the Mackenzie River delta and the Canadian arctic archipelago presents the problem of deciding on the best means of transporting this oil to market areas. The two main possibilities are tankers and pipelines. After due consideration it seems that the pipeline is more feasible although many questions remain to be answered. There is considerable speculation by many people on the best methods of building a pipeline in the North over permafrost terrain. The purpose of this paper is to attempt to bring together the various ideas on the problems involved and the presently available proposals for coping with these problems. The author does not pretend to have the final answers but it is felt that there is a need to assemble the current information for further consideration.

The first consideration is the cost of a pipeline. It appears that oil production at Prudhoe Bay may reach a value of one billion dollars per year. A pipeline from this area up the Mackenzie River valley to Edmonton and into the midwest of the United States might cost five hundred million dollars or even as much as 1.7 billion dollars. With these large potential expenditures and considering that perhaps one-half of one per cent of this money could be available for research, it should be possible to carry out investigations which must be done in order to solve the technological problems. Thus, the decision on whether to use tankers or pipelines to transport the oil from the North must depend on location of markets and technological considerations which affect both the pipeline and the ship. For the purposes of this permafrost meeting only the pipeline will be considered.

The second consideration is the route. The Mackenzie River valley seems to be a potential route particularly if oil is discovered in the Mackenzie River delta; however, Prudhoe Bay oil maybe transported by a pipeline constructed across Alaska[2]. Even so it has been pointed out that the mid-continental North American region will be an oil deficit area of about 28 per cent ten years from now - i.e. the Chicago-Midwest

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[1] This paper is a summary of a verbal presentation given at the Third Canadian Conference on Permafrost on January 15, 1969 in Calgary, Alberta.

[2] This decision was announced shortly after this paper was presented.

market will require in ten years 28 per cent more oil and the Mackenzie River valley appears to be a feasible route for oil from the northern oil-fields to fill this demand. If this route is considered with respect to the distribution of permafrost, it can be seen that from Prudhoe Bay to Arctic Red River, N.W.T., on the Mackenzie River is approximately 450 miles and runs through a zone of continuous permafrost. From Arctic Red River through the discontinuous zone to the southern limit of the permafrost is approximately 1,000 miles and to Edmonton is an additional 250 to 300 miles. Therefore, approximately 1,500 miles of the route is in the permafrost region where special problems will be encountered.

If the decision is made that some of the oil production will go to European markets, it may go by tanker through the Northwest Passage or it would go by pipeline from Prudhoe Bay to Arctic Red River thence to Churchill on Hudson Bay. It is interesting to note that the distance from Arctic Red River to Churchill is approximately the same, 1,250 miles, as Arctic Red River to Edmonton. It appears to be reasonably certain that it would be possible to ship oil from Churchill by sea to any continental port throughout the year.

Another important consideration is the design of the pipeline. In the continuous zone, permafrost occurs everywhere beneath the surface and it is known that it will be encountered along the entire route in this zone. In the discontinuous zone, however, the distribution of permafrost is patchy and unpredictable. The temperature of the perennially frozen ground is only a few tenths to approximately one degree below the freezing (or melting) point; furthermore it is in a very delicate state of thermal equilibrium with its environment and any disturbance will cause thawing and degradation of the permafrost. Large quantities of ice, up to 1,000 per cent moisture content by weight, in the form of layers, lenses and irregular bodies occur in the permafrost, which when thawed convert the rock-like frozen soils into slurries with little or no strength. It has earlier been pointed out that this sort of condition occurs along approximately 1,000 miles of the potential pipeline route in the Mackenzie River valley.

In effect, the problem is to lay a 36 or 42 inch pipeline on a soil which could turn to slurry with little or no bearing strength. The loads involved amount to approximately 500 pounds per running foot for a Bunker "C" type fuel plus the line itself which is about 200 pounds per running foot, depending on the grade and weight of the steel. This adds to 700 pounds per running foot or about 2,000 pounds in 3 feet. This is a fairly heavy load even on moist stable soil particularly for a line of circular rather than square cross-section. The problem is thus really thermal and one that has to be solved - how can a pipeline be built over discontinuous permafrost without disturbing the thermal regime of the ground?

A proposal has been made to lay the pipeline at the bottom of the Mackenzie River. This idea has some merit because it would eliminate the permafrost problem. The pipeline, however, would be subjected to large stresses due to channel shifting and scouring. Furthermore, if a break did occur and released large quantities of oil into the river, it could cause serious pollution problems and danger to wildlife, with the consequent political repercussions. The important feature about the Mackenzie River, however, is that it may well be the only readily available source of unfrozen gravel and fill. Thus, it appears quite possible that the pipeline would closely follow the river.

Because it is basically a thermal problem, no matter how the line is constructed, insulation will be a factor. This could be provided, in various ways, by fill, wood chips, styrofoam, etc. If the insulation problem cannot be satisfactorily solved, the temperature of the oil in the line will have to be held down to 28° to 30°F to maintain soil stability. The feasibility of this measure will depend on the viscosity and wax content of the oil. It is possible that some sort of cooling system to reduce the oil temperature to this level can be devised but certainly a viscosity breaker will have to be installed near the head of the line at Prudhoe Bay or the Mackenzie River delta. At Maracaibo, Venezuela, for example, it is difficult to pump at a temperature even as low as 90°F due to the high wax content necessitating the installation of a dewaxing plant. In the normal system, the customary procedure is to use some of the oil or most of the crude passing through the line as a coolant for the diesel or picking up the waste heat from the gas turbine units in order to decrease head losses in the pumping stations. In this case an increase of 7°F can take place across the line at pumping stations. However, a temperature rise of only one-half to one degree will take place using normal air or water cooling for the pump engines. There will of course be a high thermal load on the foundations of the pumping stations but no undue difficulties are seen here.

With the above in mind there appear to be three possible solutions to building a pipeline in permafrost terrain. These ideas have been proposed and discussed by a number of individuals involved in solving this problem. The first appears the most logical which is in effect to build a road along the proposed route with perhaps a 22 foot wide crown, place the pipeline along one side of the road embankment, cover the pipe with fill and the appropriate amount of insulation and use the remainder of the road for access of service and maintenance vehicles. There is some speculation that this method may be illegal but it appears the law applies only to high pressure gas pipelines and not necessarily to oil pipelines. The permafrost table should then rise into the road embankment to provide additional stability. The problem therefore is to calculate the thermal conductivity or k value of the fill, the thermal load of the oil on the line at a temperature of 28° or 30°F, and the amount and type of insulation required to maintain these temperatures in the fill itself which will then be one or two degrees below the freezing point thus maintaining the permafrost.

The second method is to lay the pipe in a trench in the active layer or in the permafrost itself. Difficulties arise here because excavation causes disturbance of the ground thermal regime and thawing of the permafrost. Trenching in perennially frozen ground is also slow and laborious. This method may have some application in the discontinuous zone where the pipe could be laid in the ground at a depth of perhaps 3 to 6 feet and surrounded with backfill of wood chips or "foamed in place" insulation.

The third method is to suspend the pipeline above ground on piles and insulate it. The Russians have experimented with this method for gas pipelines and in fact have one line in operation. One problem is that the line would be subjected to the ambient air temperatures throughout the year which may range from -60° to +80°F. This would subject the line to extremely large thermal stresses and volume changes not normally experienced by the use of a buried line. The pumping situation is, of course, complicated by such a vast range of operating temperatures. Furthermore, a very large number of piles would be required to carry the line through the permafrost region. If piles were installed at 100 foot intervals which would result in 53,000 piles for 1,000 miles and possibly more than 100,000 might be required.

The first method, that of building road and burying the pipe at one side of the embankment, seems most feasible of the three proposals. This road could be made part of the road system into the North. As has been mentioned before the best route would appear to lie along the Mackenzie River valley near the river since unfrozen gravel could be obtained from the river and stockpiled for use in construction of the road.

These are some of the problems and possible solutions but no one has actually constructed a pipeline in the North and operated it. The Canol pipeline from Norman Wells did operate at the end of the Second World War but this was a small diameter line - 4 inches - laid on the ground surface, which in no manner resembles the large diameter pipelines now being discussed.

The first applied research task will then be to build a test line or lines in the North and subject them to the thermal loads which can be expected on the pipelines with or without cooling systems or viscosity breakers. This will enable the engineers to ascertain just what occurs in the permafrost when each of these solutions are tried. These tests will of course have to be done in areas of continuous permafrost and discontinuous permafrost.

The second task will be to select the route. This will require a very careful site investigation particularly in the discontinuous zone where the distribution of permafrost is erratic and unpredictable. It will not be sufficient to make subsurface observations at regular intervals along a general route about twenty miles in width. Detailed observations will have to be carried out in different types of terrain in a narrow band one mile or less in width, where a variety of permafrost conditions occur, so as to assess exactly what problems will be encountered. Conditions will vary along the route because of the patchy distribution of the permafrost and the vegetation cover. It may be possible to bypass or circumvent some areas with severe permafrost conditions.

The third and most important task is surely to solve the thermal problems. What thermal load can be placed on the pipeline using the three solutions proposed? How much fill, gravel, insulation, etc., will be required? It is essential that delegates at this Conference consider the economics of the various methods of construction mentioned above such as balancing thermal loads against viscosity considerations and head losses[1].

The purpose of this paper has been to present some of the major considerations involved in designing, constructing and operating pipelines in permafrost terrain. It is hoped that the ideas presented here will stimulate further discussion and action in Canada on this vital problem which is nowhere near solution.

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Discussion

Mr. H. A. Leavitt remarked that large tankers were mentioned as a possible means of transporting oil out of the North and he asked why no mention was made of nuclear submarines for this purpose.
Mr. Harwood replied that nuclear ships are difficult to maintain and expensive to build. A large tanker, even modified for icebreaking, can be built in Japan for approximately $125.00 per ton but submarines with nuclear power plants would cost $700.00 to $800.00 per ton. The size

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[1] Since this paper was presented it appears that the idea of a viscosity breaker and a cooling system has been abandoned for the Trans Alaska Line for a variety of reasons not the least being the problem encountered in the disposal of the waxes. Here the solution appears to be a pile foundation.

of ship being proposed for oil transport through the Northwest Passage exceeds 100,000 tons; the same tonnage in a submarine would present special difficulties. For example, large tankers up to 250,000 tons have a draft of as much as 70 feet which prevents them from entering most ports and they have to unload offshore. Because submarines are circular, such underwater tankers of similar capacity would have a draft exceeding 100 feet which would make unloading even more difficult. Thus it is a complex situation but the economic considerations are the main factor mitigating against nuclear submarine tankers at the present time.