Abstract. The paper presents a comparison of geological and geotechnical conditions along several possible routes of the transcontinental Talakan-Nakhodka gas and oil pipeline.

It is noted that today design organizations are not provided with sufficient materials of regional (geocryological and hydrogeological) investigations and cryogenic processes forecasting.

It is suggested that an advanced study of engineering-geocryological conditions along the route be performed with mapping at a scale not smaller than 1:1,000,000.

It is recommended that all engineering geological and technical problems associated with the construction and operation of an oil and gas pipeline should be solved based on the domestic and foreign experience gained to date from the construction in northern conditions, as well as with account for current environmental protection requirements.

The oil and gas complex as the backbone of the fuel energy industry is of great importance for economic development of any country. Several leading Russian research institutes have recently worked out a concept for energy and economic development of Siberia and for creation of an oil and gas complex in East Siberia. Within the framework of this concept, a federal program on Integrated Investigation and Development of Oil and Gas Reserves and Resources in East Siberia and Far East of Russia for the years 2004-2020 is under preparation. These issues, as well as the problems of transportation construction in the Far East were discussed in a meeting held in late February in Khabarovsky with participation of RF President Vladimir Putin.

It was stated at the meeting that an integrated approach is essential in decision-making concerning prioritization of oil and gas projects in East Siberia, transportation schemes and markets, which takes into account the hydrocarbon fields discovered in Krasnoyarsk Krai, Irkutsk Oblast and the Republic of Sakha (Yakutia).

We hope that implementation of this program and establishment of large gas and oil production centers in Yakutia will stimulate the rise of the industry, increase tax revenues, create the base for socio-economic development and improve living standards for the people of Yakutia. As the scientists who study permafrost and terrain modification in the areas of civil and industrial construction, we cannot be unconcerned about rational utilization and protection of the environment during development.

There is no consensus among the planners concerning the route of the proposed oil and gas pipeline project. There are two options, the northern route and the southern route. The President of the Republic of Sakha (Yakutia), Vyacheslav Shtyrov, and the republican government support the construction of oil and gas pipelines in a single corridor across the territory of Yakutia (the northern route). This route would originate in the Lower Floodplain and run across the Yurubchensko-Tokhomskoe, Verknochenskoe and Talakan fields, passing through our prospective hydrocarbon fields. The length of the pipeline route to a terminal at Nakhodka would be more than 6,000 km.
Demand for natural gas is high in densely populated areas of the Republic of Buryatia and Chita Oblast. Therefore the southern route has its advocators. It is hoped that the final decision will meet environmental, economic and national interests.

The proposed Talakan-Nakhodka oil and gas pipeline is a tremendous project, comparable in scale only with the Amur-Yakutsk Railway. Selection of a pipeline route and engineering geology reconnaissance along routes require a very careful and thorough approach. Sensitivity of the northern ecosystems to human impacts must be taken into consideration at the design stage. Even slight disturbances of the natural conditions can lead to major environmental disasters.

Experience shows however that the command-administrative methods are still used in our republic to approach the important problems that require comprehensive analysis. Thus, in November 1996 the Sakha (Yakutia) government headed by Y.V. Kaidyshev took a decision to commence oil production from the Talakan field and to transport oil to the nearest river port. In March 1997 the construction of a pipeline was started without any serious feasibility study.

Turning to the discussion of our main topic, we should note that much of both proposed routes lies in the zones of sporadic and discontinuous permafrost. Such permafrost conditions pose greater difficulties for construction than does continuous permafrost. In addition, solutions must be sought to the technical and environmental problems associated with laying a pipeline across large rivers, mountain passes and areas of high seismic activity.

Nearly half of the route (in both options) will traverse across the southern margin of the Siberian Platform dominated by a slightly undulating relief with flat, wet divides. This topography dictates the widespread distribution of residual and colluvial clay silts, 2 to 4 m in thickness, that form a continuous mantle on the water divides and slopes. These soils are characterized by dispersivity and thixotropy in combination with high ice contents. However, the major difficulty for the construction of an oil and gas pipeline will be posed by permafrost.

According to the permafrost distribution maps, the initial section of the pipeline passes across the southern geocryological zone with discontinuous (70-80% permafrost), sporadic (40-60%) and patchy (5-10%) permafrost. Permafrost is encountered in the valleys and water divides. Its thickness ranges from 10 to 100 m. Taliks occur under lakes and rivers, and the absence of permafrost on the slopes and divides is indicated by cedar and larch forests.

The southern route crosses high mountains - the Baikal, Verkhneangarsky, Severo-Muisky, Kodarsky and Udokansky Ranges, whereas the northern route crosses the Yablonovoy and Stanovoy Ranges. The mountain section of the northern route is much shorter.

In the mountainous areas, the distribution and thermal regime of permafrost depend on relief and slope orientation. The ground temperature is 1-2°C lower on the north-facing slopes than on the south-facing slopes. The distribution of permafrost in the high mountains demonstrates an altitudinal zonation with the permafrost temperature decreasing (approximately 0.5°C per 100 m, according to Nekrasov's data) and the permafrost thickness increasing with elevation.
Within the mountain section of the routes, there are exceptions to the altitudinal trend in the river valleys where permafrost thickness does not correspond to elevation. Open taliks are not uncommon even below small streams. During reconnaissance surveys in the intermontane-depression and river-valley sections of the transcontinental pipeline routes special attention should be given to the sites containing large ground ice bodies which had been detected by the Permafrost Institute's researchers along the Baikal-Amur Railway route.

In addition, spring and river icings are widespread in the mountainous areas. Development activities not only lead to increased activity of the existing icings, but also trigger new icing formation. Icings normally form near crossings, cuts and fills of roads. They are the result of the disruption of local hydrogeological conditions. Man-induced icings can exceed in size the natural ones.

Seasonal thawing of the ground has certain relationships which are well understood. The depth of thaw varies from 0.2 to 1.5 m or greater, depending on soil type and hydrothermal characteristics. Surface disturbance can cause a 2.5-3.0-fold increase in thaw depths and lead to adverse consequences.

The major problems for pipeline construction will be encountered in the valleys and the flat divides with boggy areas. Soil temperatures in these landscapes are normally near 0°C. The soils are plastic frozen and hence very unstable.

Thawing of ice-rich and thaw-sensitive soils will result in thermokarst, thermal erosion and other surface disturbances. It is therefore vitally important to select the most suitable areas at the reconnaissance stage.

Our opinion is that the southern route will create more problems than the northern route both from the engineering geology and environmental viewpoints. Why? First, more than 1000 km of the southern route will pass through the Baikal rift zone which is the area of high tectonic and seismic activity. This will pose complex problems related to seismic stability of the pipelines which are further complicated by the presence of sporadic and discontinuous permafrost. Second, the major portion of the oil and gas pipeline route will run across the Lake Baikal drainage and this is ecologically threatening. For example, one liter of oil can degrade one million liters of water making it unfit for living organisms and human use. Third, the southern route is much longer than the northern route.

Thus, both routes for the oil and gas pipeline are characterized by spatially and temporally variable permafrost and hydrogeological conditions. Detailed permafrost mapping of both routes at a scale not smaller than 1:1,000,000 should be undertaken. The maps must show relief (depth and degree of dissection), geologic and tectonic characteristics, lithology and thickness of Quaternary deposits, and hydrogeologic and permafrost conditions. Predictions should be made of the development of hazardous geologic and cryogenic processes, as well as of their potential activation due to human impacts. The specific environmental, climatic and engineering geological conditions, the presence of permafrost and the vulnerability of the northern nature impose special requirements with respect to construction scheduling and techniques, as well as to designs for the transcontinental gas and oil pipelines. What are the ways to solve these problems?

Construction of linear structures differs from and is more complicated than construction of "point" facilities because they traverse across diverse terrain units occurring in the region. In the areas of sporadic and discontinuous permafrost, the geological and geotechnical conditions vary greatly over a short distance.
Oil and gas industry facilities exert combined mechanical, thermal, geochemical and other effects on the environment. First and foremost the hydrogeologic and permafrost conditions are disturbed along the pipeline routes, causing a threat to the integrity of the pipelines. Feedback exists in the pipeline - environment system: the impact from the pipeline modifies the natural environment, while the altered environmental conditions lead to failure conditions and threaten pipeline integrity.

Therefore permafrost survey and forecasting, and predictive evaluation mapping as the sources of information on changing conditions are the only scientific approach to solving environmental protection issues. They provide a means for foreseeing the likely consequences of terrain impacts from human activities.

The Construction Norms and Regulations (the SNIп 2.02.04-85 Bases and Foundations on Permafrost and the SNIп 2.05.06-85 Trunk Pipelines) have been and continue to be the key design references in providing the structural safety of facilities for permafrost areas. As practice shows there have been significant soil deformations and structural damages at the facilities built according to these codes due to the changes in heat and mass transfer and in thaw depth, as well as to the active development of cryogenic processes. At the transcontinental gas and oil pipeline, such deformations can lead to large failures with serious consequences.

The current and outdated guidelines and standards have serious omissions with regard to designing linear structures placed over the areas with complicated conditions (bogs, forested wetlands, ice-rich soils, karst-prone areas, icings, slumps, landslides). There is an urgent need for revising these documents based on the latest scientific state-of-art knowledge and full environmental consideration.

In order to estimate the investments in designing oil and gas pipelines, small- and medium-scale special-purpose maps must be already in hand. In 2002, PNIIS (Production Scientific-Research Institute for Engineering Surveys & Construction of the Russian Committee for Construction) compiled a set of electronic maps, including the engineering geology map of southern East Siberia and Far East at a scale of 1:2,500,000, the engineering geology zonation map of the Russia-China and Angarsk-Nakhodka trunk pipeline routes at a scale of 1:1,000,000 and the engineering geology map of the area along the proposed southern route at a scale of 1:200,000. As yet, no such maps have been made for the northern route.

It is appropriate to refer to the experience with the trans-Alaska oil pipeline, 1,300 km in length, constructed in 1974-1977. The construction took three years and two months. First, a soil road was built along the proposed route. Its cost was US$300 million (the total project cost was US$8 billion). Twenty nine construction camps and equipment/material storage areas were placed along the road. Seventy thousand workmen were involved in the construction of the pipeline. Fifty five environmental specialists supervised the construction to assure complete compliance with the design.

The trans-Alaska pipeline system was commissioned in June 1977. There have been no major oil leaks since then. Continuous pipeline monitoring is performed along the entire route. Data are immediately sent to the system control center. Hunting is prohibited within eight kilometers at both sides from the pipeline. "In Alaska, the grave prophecies of the project's opponents did not come true", V.M.Peskov, a reporter of Komsomolskaya Pravda, wrote those days, "deer follow the same routes, birds nest in their habitats, the spawning rivers are clean, no surface impoundment has occurred. Today the trans-Alaska pipeline is an example of harmony of the technology, human intellect and the nature".
In recent years, the Permafrost Institute SB RAS has considerably expanded its knowledge aimed at providing a research service for the construction of linear structures. The specialists of our Institute participated in the construction and successful operation of such linear structures, as the Mastakh-Berge-Yakutsk gas pipeline, the Chernyshevsky-Mirnyi-Lensk and Chernyshevsky-Aikhal power transmission lines, the Baikal-Amur and Amur-Yakutsk railways, the Mirnyi-Chernyshevsky-Aikhal-Udachny gas pipeline and other projects. A large volume of data has been collected through monitoring of these structures that help understand the mechanisms involved in their interaction with the environment. Our specialists made a significant contribution to solving various problems during the engineering geology reconnaissance and construction of the Baikal-Amur railway which was laid in an area with complicated permafrost and geotectonic conditions. More than ten scientists from the Institute were awarded medals for their contribution to the BAR construction.

The Institute's research personnel are now actively involved in the preparation of many republican and federal environmental protection programs. The Laboratory of Engineering Geocryology has developed a concept of terrain and engineering protection against adverse changes of the permafrost environment in Yakutia. This document stresses that regional investigations of the geocryological and hydrogeological conditions, as well as prediction of permafrost-related processes should be made early in the project planning process. It also emphasizes the necessity for advanced engineering preparation of construction sites, inventory of disturbed areas prior to construction, monitoring of the natural environment and facilities, strict adherence to construction schedules and many other aspects. Such approach certainly will add complexity to the design and survey, as well as add extra costs to the project. However, this will be repaid during operation.

It is desired that all engineering geological and technical problems related to the construction and operation of transcontinental oil and gas pipelines would be addressed based on the domestic and foreign experience gained to date from the construction on permafrost. Reliability and environmental safety should be the underlying principles for pipeline projects.

**BIOGRAPHIES**

**Konstantinov Innokenti Petrovich**, born in 1932, is a leading scientist of the laboratory of engineering geocryology at Permafrost Institute, Siberian Branch of Russian Academy of Sciences. He graduated from Novosibirsk Engineering Construction Institute in 1957. He studies thermal interaction of pipelines with frozen ground and held a series of researches in Western Siberia that led to elaboration of certain measures of preservation and recovery of disrupted geocryological conditions. He defended Ph.D. thesis in 1969.

He took part in research work concerning creation and stabilization of ice islands at shallow water shelf and at the operating gas-main pipelines Talas-Tumus, Yakutsk-Pokrovsk and Mastakh-Yakutsk. He is an author of about 50 scientific articles.

**Gotovtsev Semen Petrovich**, born in 1950, is a senior scientist of the laboratory of regional geocryology and cryolitology of Permafrost Institute, Siberian Branch of Russian Academy of Sciences. He graduated technical and engineering department of Yakut State University with geology and mineral exploration as a main specialty. He has been working at Permafrost Institute since September 1975. He defended a thesis for academic degree in 1993, on "Specific features of frozen ground temperature formation in Yakutian diamondiferous province". He wrote about 60 scientific papers, 35 of them were published officially, including 2 treatises (in co-authorship).