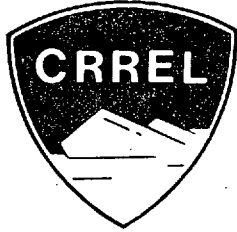


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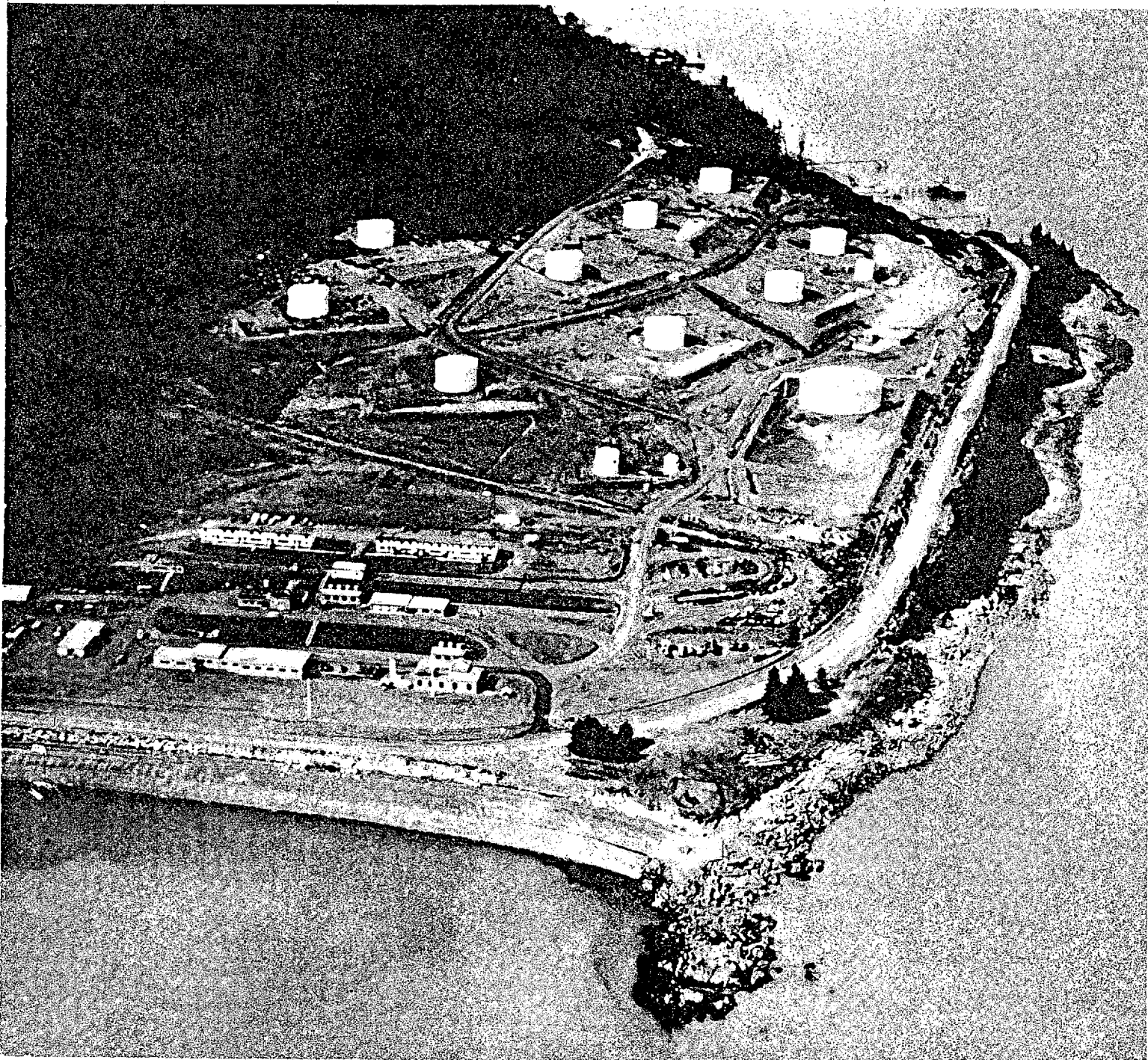


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HAINES-FAIRBANKS PIPELINE

Design, Construction and Operation

D.E. Garfield, C.E. Ashline, F.D. Haynes and H.T. Ueda



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)								
<p>This report, one of a series, is intended to provide a background for the analysis and evaluation of new pipelines being built in cold regions. Topics discussed include the initial design, construction, testing, operation and maintenance of, and modifications to, the 8-in. pipeline from the deep water port at Haines to military installations at Fairbanks, Alaska. The 626-mile multi-product pipeline began operation in 1956. The results of a corrosion survey completed in 1970 indicated that extensive renovation would be required</p>								

20. Abstract (cont'd)

to continue operations, and the section from Haines to Eielson Air Force Base was closed in 1973.

PREFACE

This report was prepared by D.E. Garfield, Research Mechanical Engineer, of the Engineering Services Branch, Technical Services Division, CRREL, C.E. Ashline, Maintenance Supervisor, Alyeska Pipeline Service, Co., F.D. Haynes, Materials Research Engineer, of the Applied Research Branch, Experimental Engineering Division, CRREL, and H.T. Ueda, Mechanical Engineer, also of the Engineering Services Branch at CRREL. Funding was provided by the Directorate of Facilities Engineering under Order No. ENG-CRREL 76-1, Acct. Classification 2162020-08-7600, P728012.3000 349-129 COCE 7282-3000, *Consolidated Trans-Alaska Pipeline Research Program*.

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Introduction

The present and proposed construction of petroleum pipelines in Alaska, such as the Trans-Alaska Pipeline, have created a renewed interest in existing pipelines which have been built in the northern areas of North America. Some of these lines, or at least sections of them, are still operational in the United States and Canada. An understanding of the problems encountered with the environment and with construction, hydrostatic testing and operation of the existing pipelines provides a valuable background for the analysis and evaluation of new pipelines being built in cold regions.

Unfortunately, much of the information on the existing pipelines is scattered and generally not well documented. This report summarizes an investigation on one of those pipelines, namely the Haines-Fairbanks Pipeline in Alaska. This is intended to be the first of a series of reports on pipelines constructed in cold regions.

General Description

The pipeline from Haines to Fairbanks came about because of fuel shortage problems in Fairbanks during World War II. During that period most of the military fuel was supplied by 3- and 4-in. lines from Skagway to Fairbanks. To meet increased fuel demands, a finished product pipeline was proposed between the deep water port of Haines in southeastern Alaska and military installations north of the Alaska Range in interior Alaska. This pipeline would transport various petroleum products, delivered by ocean barges or tankers and stored in bulk terminal facilities at Haines, to storage facilities at several locations near Fairbanks.

The entire 8-in., multi-product pipeline was in operation from 1956 to 1973. It began at Lutak Inlet about three and one-half miles north of Haines and crossed into Canada along the Haines Highway to Haines Junction. From there it followed the Alaska Highway through Tok and terminated seven miles north of Fairbanks (see Fig. 1). In its 626-mile route, the pipeline made 25 major river crossings, 82 stream crossings, 49 major highway crossings, 39 secondary road crossings, and 11 major swamp-tundra crossings. The pipeline extended over the Coastal Mountains, through the plateaus and valleys of the Yukon Territory and British Columbia, and then re-entered Alaska. Temperature extremes along the pipeline route have ranged from a low of -82°F at Snag, Yukon Territory, to a high of 92°F at Fairbanks, Alaska.

Initial Design

In 1950, Fluor Corporation contracted to design the 8-in. line. This phase of the program consumed two years.

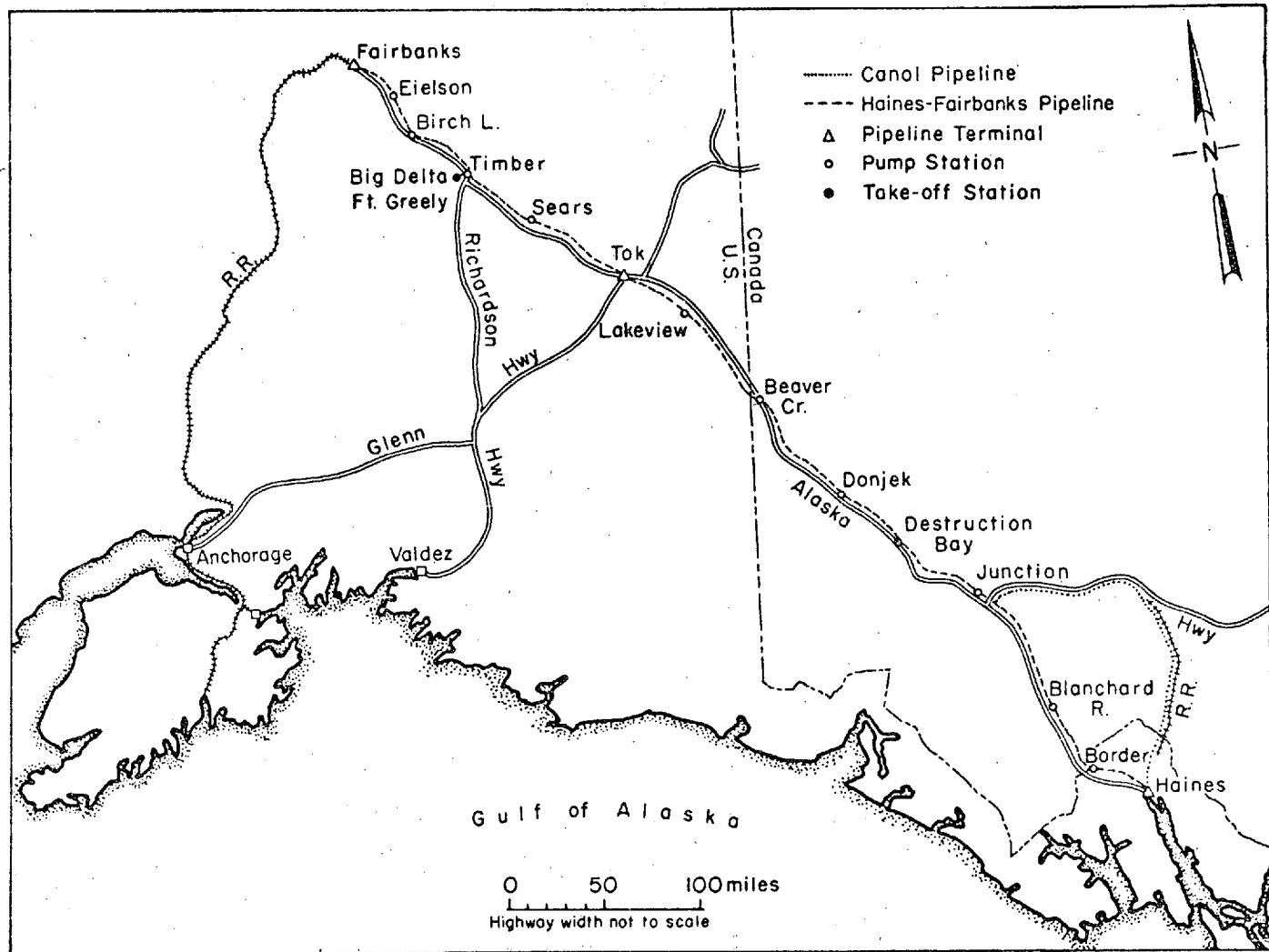


FIG. 1. Haines-Fairbanks Military Pipeline Route.

The original design criteria were based upon pumping 9600 barrels per day (BPD) of jet fuel (specific gravity 0.8205) at a temperature of -20°F. Original appurtenant facilities included five pumping stations, two intermediate takeoffs, terminal facilities at Fairbanks, two tank farms at Haines and Tok, and a steel pile pier at Haines. The five pumping stations were located at Haines, Border, Junction, Donjek and Tok (six booster stations were added in 1962, as described below). The normal throughput rate of 9600 BPD was attained with pumps operating at Haines, Border and Tok stations. Emergency throughput rates of 16,500 BPD could be attained by placing the Junction and Donjek stations on line to supplement the Haines, Border and Tok stations. Intermediate takeoffs were planned at Fort Greely and Eielson Air Force Base, and another small takeoff was added at Birch Lake.

The Haines-Fairbanks pipeline right-of-way location was selected to allow the maximum access from the existing Alaskan and Canadian highways. This route selection also allowed the use of many existing bridges for stream and river crossings. Due to favorable topography, it was possible to keep the line level in many locations. The line began at Haines at an elevation of 30 ft, with a net vertical rise of 400 ft at Fairbanks. This seemingly small grade was complicated by several peak elevations as indicated in Figure 2. These peaks greatly influenced pipe and valve selection and the design and location of pumping stations.

The original pipe material and wall thicknesses were based upon the use of the Modified Barlow Equation:

$$t = \frac{(P + 50V) D}{0.85 \times 0.875 \times 2Y} \quad (1)$$

where:

t = wall thickness, in.

P = maximum control pressure, lb/in.²

V = maximum flow velocity, ft/sec

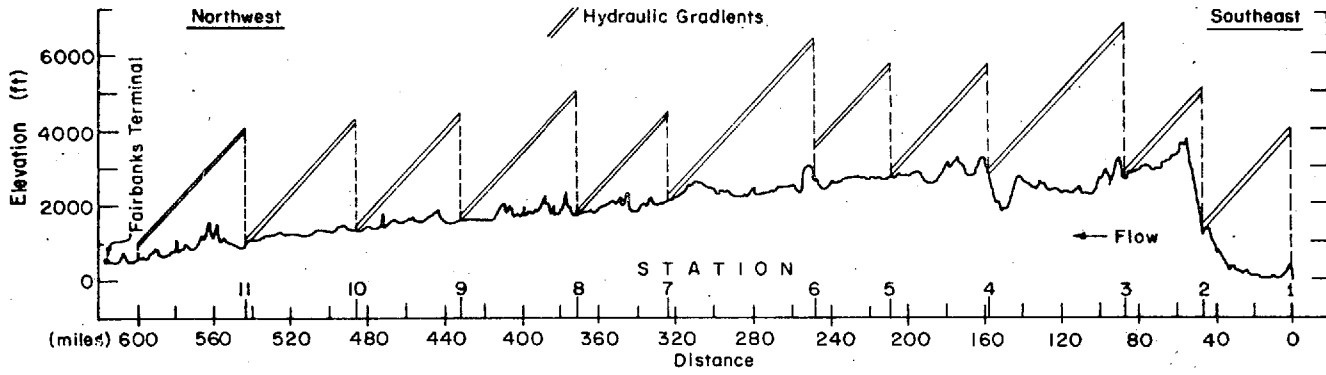
D = outside diameter of pipe, in.

Y = minimum transverse yield strength, lb/in.²

0.85 = $\frac{\text{maximum working stress}}{\text{minimum transverse yield}}$

0.875 = factor for wall thickness tolerance

50V = factor for surge pressure, lb/in.²



Sta	Location
1	Haines
2	Border
3	Blanchard River
4	Haines Junction

Sta	Location
5	Destruction Bay
6	Donjek
7	Beaver River
8	Lakeview

Sta	Location
9	Tok
10	Sears Creek
11	Timber

FIG. 2. Haines-Fairbanks Pipeline Profile, Pump Stations after Modifications, and Hydraulic Gradients.

The factor for wall thickness tolerance was included because the original specifications allowed a depth of defect or variation in wall thickness of $\pm 12.5\%$ of the nominal wall thickness.

The average fluid velocity in a pipe can be calculated from the flow-rate by:

$$\bar{V} = \frac{Q}{A} \quad (2)$$

where:

\bar{V} = average velocity, ft/sec

Q = average flow rate, ft³/sec

A = average internal pipe cross-sectional area, ft².

Average fluid velocity, \bar{V} , for a flow rate of 9600 BPD in an 8-in.-I.D. pipe is 1.787 ft/sec.

Substituting in eq. 1, the maximum line pressure for the 8.625-in. outside diameter pipe having a minimum yield strength of 30,000 lb/in.² and a wall thickness of 0.277 in. is

$$P = \frac{0.85 \times 0.875 \times 2 \times 30000 \times 0.277}{8.625} - 50 (1.787)$$

$$P = 1344 \text{ lb/in.}^2$$

Likewise, for the standard 0.322-in. wall thickness pipe, the allowable pressure, P , is 1577 lb/in.².

The line pipe specified for the Haines to Fairbanks line was API 5L Grade A Seamless, with a specified minimum yield strength of 30,000 lb/in.² Most of the mainline pipe was of 0.277-in. wall thickness. At most underwater crossings, 0.322-in. wall pipe used. For a distance of about 4 miles after Border Station, B.C., Canada, 0.322-in. wall pipe was used.

Initially, the pipeline was intended to operate under normal conditions with only Haines, Border, and Tok Pump Stations in operation. The pumps at Haines were positive displacement types, while those at Border were centrifugal types, acting as boosters. Products were separated and stored at Tok Station and pumped on to Fairbanks with positive displacement pumps. When emergency throughput was required, additional centrifugal pumps at Junction and Donjek Stations were operated. Each site included housing, maintenance and supporting

facilities for the station. In addition, storage capabilities were provided at Haines and Tok Stations.

Construction

Original bids on the project called for 615 miles of 8.625-in.-O.D. pipe with two wall thicknesses of 0.277 and 0.322-in. Storage facilities for the pipeline were to consist of two tank farms: one at Haines with 9 tanks totaling 270,000 bbl and one at Tok, also with 9 tanks totaling 270,000 bbl. The construction was to start in November 1953 and be completed in September 1955.

The contract was awarded in early November 1953, at a total contracted cost of \$29,001,287. The successful bid was submitted jointly by Williams Brothers Co., Tulsa, Oklahoma; McLaughlin, Inc., Great Falls, Montana; and Morrel Construction Co., Vancouver, British Columbia.

A subcontractor, Oaks Construction Co., Anchorage, began clearing operations almost immediately. Thirty feet of the 50-ft right-of-way was cleared of trees and brush. Initial clearing began by using two Caterpillar D-8 bulldozers at Ladd Air Force Base in Fairbanks. Two more D-8's began working in opposite directions out of Tok on 1 January 1954. A fifth unit began working northward from Scotty Creek at the Canadian border. Each unit cleared an average of about a mile a day during early 1954. During February, temperatures dropped from -30°F to -60°F, bringing most work to a standstill. One crew with two dozers kept working, however, by rigging tarpaulins around the tractor so that the heat of the engine would keep the controls and the operator warm. At night the tractors were entirely covered with tarpaulins, and eight kerosene lanterns were placed under each tarpaulin to provide enough heat to start the tractors the next morning. When the weather improved, all five crews returned to work, clearing and draining an average of 2.5 miles per day each. At one point clearing crews used a method employed at Hungry Horse Dam a few years earlier. A steel ball 7 ft in diameter was filled with water to a total weight of 10 to 12 tons, rigged with heavy wire rope and swivels, and towed by two and sometimes four tractors. This method reportedly cleared brush and small trees at a rapid rate.

Seamless pipe for the Alaskan part of the route was purchased from National Pipe Co., while the part of the pipeline in Canada used British pipe. Pipe was delivered by ship to docks at Haines and Valdez, Alaska. The unprotected pipe was unloaded and rolled into nested stacks 8 and 9 pipes deep. The pipe was not sorted according to wall thickness. No cribbing was used beneath the pipe stacks during storage. Pipe was transported from the docks by logging trucks and stockpiled every 5 miles along the pipeline route. Stringing pipe along the right-of-way began in mid-April, using trucks and skids. Trucks were loaded and unloaded using mainly Caterpillar D-6's equipped with Trackson Pipe Layer sidebooms.

A week after pipeline stringing had begun, the first welding crew began work. The pipe was picked up by a Caterpillar HT-4 front end loader and the pipe ends were burnished. Two D-6 Caterpillars with sidebooms worked in tandem, hoisting the pipe into position along the line. These were followed by two D-6's, each equipped with two Lincoln electric welders. Weld production reached over 500 joints per day, averaging 2 miles of completed line per day, and occasionally 4 miles per day were completed.

Five teams of weld inspectors inspected each weld using isotope cameras. Most of the line (478 miles) was installed aboveground, while the remainder (148 miles) was buried. The aboveground sections were laid directly on the ground, except in swamp areas where timber cribbing was used in order to retain natural drainage channels. All turns were accomplished with bend radii of at least 40 ft. Transitions from above to below ground were placed without regard to soil conditions which may affect pipe corrosion. The major buried sections of the line included 42 miles northward from Haines terminal and 96 miles northward from Big Delta to the Fairbanks terminal. These sections were buried with approximately 30 in. of cover. The remainder of the total 148 miles of buried line consisted of short buried sections along the route intended to protect station personnel, equipment, and the line from possible vehicular damage and from washouts due to flash floods. An attempt was made to maintain a minimum depth of 3 ft to the top of the pipe when trenching with the pipeline trenching machine. A novel method, at least at that time, of laying pipe was used in the buried pipeline sections. The pipe was welded before it was installed in the ditch, so that it could be welded before the frozen mud and muck could slough off the trench walls. On bridge crossings the pipe was roller mounted, with "S" bends ranging from 3 ft to 40 ft in radius, before the pipe went underground at the bridge abutments.

Major construction problems were encountered in swamps, muskeg, and areas where ditching was necessary. Test borings indicated that permafrost was present at some locations at various depths and in varying thicknesses. In some areas there was permafrost immediately below the surface, and in others it began 15 to 20 ft down. A Cleveland 320 trencher powered by a Caterpillar D-8800 engine was modified for operation in frozen ground. A small heavy duty wheel with a total of 14 "Jiffy" buckets was installed. Five- and six-inch "Jiffy" roter teeth were placed alternately on each bucket. A D-8 tractor hitched to the trencher provided additional tractive power. Progress was slow but steady, and new teeth had to be installed for every shift.

Equipment normally used for hauling, excavating, welding, laying pipe, and backfilling had difficulty traversing the pipeline right-of-way. Part of this problem was caused by the clearing method of pushing debris of trees, spoil material, rocks, etc., to the edges of the right-of-way.

No immediate effect was noticed, but after the first spring runoff, silt settled from the stacked material, creating dikes. These dikes changed water drainage patterns, causing construction problems, and later initiated pipe settlement.

The major portion of the job was completed during the 1954 construction season, leaving major river crossings and some pumping stations for completion in 1955. Maximum employment during the peak of construction was 775 men. Construction was in accordance with the American Petroleum Institute Standards and Recommended Practices, API Specifications:

- Std 602 - Small Carbon Steel Gate Valves
- Std 6D - Pipeline Valves
- Std 599 - Steel Plug Valves
- Std 600 - Steel Gate Valves
- Std 1104 - Welding Pipeline and Related Facilities
- RP 1107 - Recommended Pipeline Maintenance Welding Practices.

Original construction was completed in the summer of 1955 at a total cost of \$38,249,796. This represents a 32% cost overrun. The completed length of the pipeline was 626 miles, 11 miles longer than originally planned, partially because the line was run around rather than across 290-ft-deep Kluane Lake.

Testing

After construction was completed in the late summer of 1955, water was pumped into the line for hydrostatic testing. Enough water was pumped into the line to extend for 200 miles, followed by a batch of diesel fuel, and this followed by a batch of jet fuel. Test pressures were 1500 lb/in² on the Alaskan portion of the line and 1900 lb/in² on the Canadian portion. Four ruptures developed in the Canadian portion, and several damaged sections were discovered on the Alaskan portion, mainly caused by tractors running over the pipeline. Repairs were made and hydraulic testing was completed in August.

The pipeline was operated by Williams Brothers Co. until the United States Army, Alaska accepted the pipeline and facilities on 12 October 1955.

At some time after Army acceptance, it was discovered that the pipeline was blocked. Pipeline scrapers had not been used to displace

the water from the pipeline, leaving behind sufficient water in the valleys of the pipeline to plug the line when frozen. Army personnel determined that the line was blocked downstream from Junction Pump Station. The Army attempted to remove some of the ice blockage by lighting wood fires under the suspected blockages. They cut the pipeline in seven locations, but attempts to purge the line were unsuccessful.

A contract was awarded to assist in purging the pipeline, and full-scale purging operations began on 23 January 1956. To locate blockages a chart was prepared which showed expected static pressures at all gate and check valves and other locations when 1000 lb/in.² was maintained at the upstream pump station. Pressure readings were made at valve locations where pressure taps were installed during pipeline construction. When a measured pressure reading was lower than predicted, it was assumed that the blockage was between that location and the location of the previous correct reading. A "hot tap" (a pipeline device which allows tapping into a line while it is under pressure) was welded to the pipeline midway between these two locations and a pressure measurement made to further pinpoint the blockage. This process was repeated until the blockage was located to within a mile. Then men would walk the pipeline, striking it with 10-lb hammers. A sharp ring indicated a clear pipe, while a dull thud indicated the presence of an ice plug.

When the ice was located, the pump pressure at Junction Station, the nearest pump station upstream from the blockage, was lowered and gate valves both upstream and downstream from the plug were closed. A "hot tap" was installed just downstream from the plug and a pressure gage installed to indicate line pressure during cutting operations. Communications with the valve and pump station operators were critical during the purging period.

Most attempts to construct a collection basin for the fuel were unsuccessful, since the ground was frozen. Troughs were cut in the snow to divert fuel from the right-of-way because of the fire hazard when welding the pipe. The pipeline was moved beyond the right-of-way area by sideboom tractors and then the line was cut. After the downstream end was drained, it was moved back onto the right-of-way and a weld-end installed while the upstream end of the line was being purged.

Purging operations were directed from the purging site. Sideboom tractors equipped with cradles raised the pipe 4 to 5 feet in the air and moved along the right-of-way attempting to break up the ice by flexing the pipe. Preparations were made to light brush fires beneath the pipe during this period. After flexing the pipe, all upstream pumps were put on line and set for maximum output. Just before the pumps would shut off automatically due to high pressure, men at the upstream valve were directed to open the valve. Simultaneously, the brush crew ignited their brush piles. Purging was discontinued when the line ap-

peared cleared or when it was determined that the terrain could not safely hold more fuel. In the latter case, the line would be welded and a cut made in another location.

The cut pipe ends were tied together, and before final welding the downstream valve was opened. The upstream valve was then opened while station operators monitored line pressure. When a pressure drop was observed at the station, pumping at a reduced rate began. This rate was adjusted to maintain 350 lb/in.² at the weld end, which allowed bleeding air from the line through the "hot taps" installed earlier.

When pressure at the weld section reached the required level, the weld operation was completed. This operation was repeated 28 times between points 195.8 to 382.5 miles from Haines. Occasionally, the method did not work on the first attempt, in which case the flexing and brush fires were continued until the line was purged.

After the removal of one or more ice obstructions, the product could be received at reduced rates at Tok Station. After a period of time varying from immediately up to several days, pumping would continue until another blockage occurred downstream from the previous one. After a 10-day shutdown period to wait for resupply at Haines Terminal, pumping operations finally reached normal on 3 April 1956. A number of important observations were drawn from this operation:

- 1) Water should not be allowed to accumulate in the pipeline when there is danger of freezing.
- 2) Since most of the ice blockages were not solid ice masses, large pipeline flows created enough pressure drop across the blockages to transport them down the pipe; small pipeline flows would not move the blockages and the fuel pumped past the blockages was simply pumped onto the ground. (500 BPH minimum recommended on an 8-in. pipe.)
- 3) The pipe must be cut before attempting to thaw the ice or larger, more solid obstructions may form.
- 4) Flexing the pipe using cradles from side boom tractors was very effective in breaking up obstructions.
- 5) Communications were absolutely essential for proper valve and pump sequencing.
- 6) The use of alcohol was not adequately tested for removing ice blockages; however, it was felt that considerable time was required before noticeable effects would be observed.

Operation

The pipeline was designed to transport finished petroleum products. The original design required transporting the following fuels: diesel fuel, Arctic Grade C; aircraft turbine and jet fuel, JP-3; motor vehicle gasoline, Grade 72 octane; aircraft reciprocating engine fuel, Grade 115/145. These products were pumped through in "batches," with no mechanical separation between batches.

The Dispatch Division at Fort Richardson, Alaska, maintained supervisory control over all products dispatched through the pipeline. The entire pipeline was monitored at a manually operated control board which presented the pipeline in graphic form. The control board consisted of three parts: (1) a paper tape scaled to 1/8 in. per 100 barrels, (2) a pipeline scale profile, and (3) devices to determine volume variations due to changes in operating temperatures and pressures. The paper tape was used to plot the displacement of the products in the line by batches, corrected to all operating variables including time of entry into the line and specific gravity of the product. At hourly intervals this color-coded tape was manually advanced in the direction of product flow a distance equal to the net quantity of product pumped into the line. The control board was operated in conjunction with a telephone-teletype communication system to all pipeline stations and served as the control center for product movement operation.

All products were delivered to terminal storage at Tok Terminal. From Tok the products were pumped through the main line to either Eielson Air Force Base or the Fairbanks Terminal. The product could also be removed by "sampling" the batches as they moved through the main line, and it could be stored in tanks at the Fort Greely Take-off Station and Birch Lake Tank Farm.

The pipeline condition was monitored by weekly round-trip flights from Haines to Tok or Haines to Fairbanks. These flights were made by civilian aircraft under government contract. If the pilot observed any leaks or other condition requiring immediate attention, he would radio the nearest pump station or terminal so that they could take remedial action.

Maintenance

According to some sources, pipeline wear due to scouring was a potential problem, particularly where the pipe was laid over rocky ground. Ambient temperature variations caused the pipe to expand and contract, with resulting lateral movement of the pipe over the soil. A sample calculation is included in Appendix A to show that this could indeed be a problem.

Other external pipeline maintenance included repair of washouts, removal of debris, tree cutting, etc. These jobs were performed mainly to improve or maintain drainage patterns on the pipeline right-of-way.

Since the Haines-to-Fairbanks pipeline was a finished product line, there were no waxing problems. Pipeline scrapers (pigs) were used primarily to remove water and sediment accumulations in the pipeline. To prevent corrosion inhibitor removal from internal pipeline walls, all-cup polyurethane pigs were used, unless the presence of sediments indicated that a combination wire brush and rubber cup pig should be used. To minimize the amount of water pumped into the pipeline, during summer operations water was removed daily from the bottom of all storage tanks. Filter/separators at Haines and Tok were excelsior-filled types, which had limited sediment filtration and water retention capabilities. When temperatures at Tok were much lower than at Haines, water in the pipeline turned into ice particles and clogged the strainers at Tok.

A 12-mile section of pipe, part of it running under the Klukshu River in Canada, was replaced in 1970. Because of the impact the construction had on the Alaskan and Canadian fishing industry, many precautions were taken. The river had to be diverted, the salmon "herded" through the diversion, and then herded back to the original channel when construction was completed. About 10,000 gallons of fuel were drained from the line and trucked 120 miles to Haines, Alaska. The pipe was thoroughly tested before and after installation in the line. Extensive paperwork was involved - accounting to customs officials for all material brought into Canada and returned to Alaska when construction was completed. Wildlife officials from both nations were satisfied with the precautions taken during this reconstruction.

Design of Modifications

Projected fuel usage requirements increased, so in 1961 a redesign was initiated which would increase maximum throughput capability from 16,500 barrels per day to 27,500 barrels per day. Based on the results of a previous design study and on previous operating experience, the following major mechanical requirements were levied: (1) the throughput was to be based on JP-4 fuel at -5°F flowing through the existing 8-in line; (2) maximum pipeline stresses would conform to American Standards Association Standard B31.4, "Oil Transportation Piping," except for a six-mile segment downstream from Haines Station; (3) a maximum of six new pump stations would be installed, with each station consisting of no more than three centrifugal pumping units; (4) no standby pumps would be installed; (5) existing pumping stations would remain unchanged, except Border Station, which might require one additional pump; (6) space would be provided for strainers to effectively remove water from fuel at Haines and Tok Stations; (7) the required construction completion date would be 30 September 1962. Due to the urgency of this project, the new facilities were to be considered temporary construction.

In this redesign, allowable pipeline pressures were calculated using equilibrium equations for a thin-walled cylinder, as given in ASA B31.4:

$$t = \frac{PD}{2S} \quad (3)$$

where:

t = design thickness of pipe wall, in.

P = maximum internal design pressure, lb/in².

D = outside diameter of pipe, in.

S = maximum allowable hoop stress in the pipe wall, lb/in².

For the pipe used on the Haines-Fairbanks line, a joint efficiency of 100% was required, which permitted a maximum allowable hoop stress of 0.72 times the minimum yield strength of the pipe. The maximum working stress for the API 5L Grade A seamless pipe (yield strength 30,000 lb/in²) was 21,600 lb/in². The maximum pressures for the three pipe wall thicknesses used as calculated from eq. 3 were: 1387 lb/in² for the 0.277-in. wall thickness, and 1613 lb/in² for the 0.322-in. wall thickness. The design pressures based on the thin-walled cylinder equation were less conservative than when based on the Modified Barlow Equation used in the original design.

The hydraulic gradient profile was calculated for the entire pipeline (Fig. 2). The Reynolds number was calculated based on the following equation:

$$Re = \frac{50.7 \rho Q}{d\mu} \quad (4)$$

where:

Re = Reynolds number

Q = flow rate, gal/min

ρ = fluid density, lb/ft³

d = internal pipe diameter, in.

μ = fluid absolute viscosity, cp.

Substituting the appropriate values for 800 gpm of JP-4 flowing at -5°F ($\rho = 51.3733$ lb/ft³, $\mu = 1.778$ cp) through the 8.071-in.-I.D. pipe, the resulting Reynolds number was 145,200, indicating turbulent flow. A friction factor of 0.018 was selected. The pressure drop per 100 ft

of pipe was calculated from

$$\Delta P_{100} = 0.129 \frac{f \rho \bar{V}^2}{d} \quad (5)$$

where:

- ΔP_{100} = pressure drop per 100 lineal feet of pipe, lb/in.²
f = friction factor
 ρ = fluid density lb/ft³
 \bar{V} = average fluid velocity, ft/sec
d = internal pipe diameter, in.

The resulting pressure drop was found to be 0.37202 lb/in.² per 100 lineal feet or 19.6427 lb/in.² per mile. This converted to an equivalent frictional head loss of 55.0585 ft of JP-4 per mile of pipeline.

These pressure drop figures, together with elevation data, required pump suction pressures, and estimated station pressure drops were used to determine the location of new pump stations and to determine the adequacy of existing pump stations. Efficiencies of 90% for plunger pumps and 79% for centrifugal pumps were assumed.

The engineering study indicated that the five existing pump stations were adequate, provided six additional booster stations were added to the pipeline. These booster stations were constructed at Blanchard River (Milepost 87), Destruction Bay (Milepost 208.9), Beaver Creek (Milepost 323.8), Lakeview (Milepost 371.1), Sears Creek (Milepost 485.8), and Timber (Milepost 544). This portion of the pipeline was completed at a total cost of \$5,500,000.

The fuels transported through the upgraded pipeline included diesel fuel, Grade DFA; aircraft turbine and jet engine fuel, Grade JP-4; automotive combat gasoline, Grade 95C; and aviation gasoline, Grade 115/145. When in operation, 210,000 barrels of petroleum products were contained in the lines.

Cathodic Protection and Corrosion Surveys

Besides the cuts to remove ice from the line during initial testing, twelve pipeline failures occurred from 1956 to 1970. Bullet holes and corrosion caused most of the failures, with corrosion alone accounting for six failures. The pipe was not wrapped or coated for protection against external corrosion. Where soil resistivity indicated potential corrosion problems, cathodic protection was installed. A soil resistivity

survey performed in 1957 indicated that most of the pipeline was in contact with soils of high resistivity, and that only an extremely small portion of the line was in soil that could be considered more than mildly corrosive. The data obtained also indicated that galvanic anodes could be used successfully on only a small part of the line. None of the soils tested on any of the four tank farms was of sufficiently low resistivity to be considered corrosive.

The Haines Dock and related facilities were protected by magnesium anode beds and rectifier controls. Due to large cyclic variations in total circuit resistance caused by tides and the variation in water salinity, the corrosion protection was only partially effective at Haines.

Another inspection of the pipeline between Haines and Border stations was performed in 1968 by AMF Tuboscope, Incorporated. This inspection was accomplished by a new technique which used an instrumented pig (Linalog survey instrument) to record the location of pits in the internal or external pipe walls. The results of this survey indicated extensive corrosion damage. Tuboscope inspection of the northern section of the pipeline was completed in 1970. This survey indicated the northern section to be generally in good condition.

Present Status

As a result of the corrosion survey several miles of pipe were replaced in the southern section. It became increasingly evident that extensive rehabilitation would be required to maintain pipeline operation.

The pipeline from Haines to Eielson Air Force Base was closed in 1973. The 27-mile section of the pipeline between Fairbanks and Eielson was retained to supply Eielson with the product delivered to Fairbanks by rail from Anchorage.

Summary

The Haines-Fairbanks Pipeline was considered an economic asset from its very beginning. A 1960 report cited annual savings in transportation costs in excess of \$3.5 million. During FY 1970 the pipeline transported 1.3 million barrels of JP-4 and 54.6 million barrels of gasoline for support of "Combat Pacer" (Vietnam flights) plus Alaskan Air Command and Army aviation operations in Alaska.

During construction, few environmental precautions were recorded. Standard procedures for building a safe line were followed, however, mainly because of the value of the product being transported.

Many problems occurred because of the arctic climate and the urgency of the project. Because of the temporary nature of some of the pipeline construction, a vigorous program providing for the protection and longevity of the pipeline was not pursued.

An evaluation of the design, construction and operation of the Haines-Fairbanks pipeline enables the following observations to be made. Construction of pipeline right-of-ways must be carefully planned to prevent drainage problems and prevent pipe settlement. Prevention of corrosion by wrapping the pipe and by cathodic protection appears to be economically justified in prolonging pipeline longevity. After hydrostatic testing is completed, scraper pigs should be used to purge the line of test water. The removal of blockages due to freezing of residual test water in the Haines-Fairbanks line was an expensive operation. Purging the line of test water also helps to prevent internal corrosion. A pipeline exposed to severe temperature differences in the Arctic must be carefully designed for thermal expansion. Pipe movement due to thermal expansion required maintenance on the Haines-Fairbanks line.

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Appendix A

Lateral Pipeline Movement Due to Thermal Expansion

To determine if thermal expansion of a pipeline could cause sufficient movement of the surface-laid pipe over the soil, the following calculations were made. The calculations are based on a temperature excursion of 130°F (e.g. from -50°F to +80°F) and steel pipe with a linear coefficient of thermal expansion, α , of $6 \times 10^{-6}/^{\circ}\text{F}$.

If we take a one-mile length of pipe, the linear expansion is only:

$$\delta = \alpha c \Delta T$$

where:

δ = change in length, ft.

α = coefficient of thermal expansion, ft/ft/°F

ΔT = temperature change, °F

c = initial pipeline length, ft.

For this example, it is found that the one mile length expands only 4.12 ft. with a 130°F temperature rise which, in itself, is not enough movement to cause significant scouring.

Referring to Fig. A1, suppose now we assume that the ends of this one-mile length of straight pipe ($c=5280$ ft) are anchored, and the pipe is free to move laterally. What maximum movement, h , could occur due to a 130°F temperature rise if it is assumed that the final configuration of the pipeline centerline is a circular segment of length, s , and unknown radius, R ?

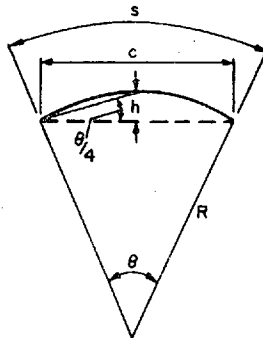


Figure A1. Assumed pipeline configuration.

For the example, $c = 5280$ ft and $s = c + \delta = 5284.12$ ft. From Fig. A1, $s = R\theta = 5284.12$ ft and $\sin \theta/2 = \frac{c}{2R} = \frac{5280}{2R}$. Combining these two equations:

$$\frac{\sin \frac{\theta}{2}}{\frac{\theta}{2}} = \frac{5280}{5284.12}.$$

Let $X = \frac{\theta}{2}$ so

$$\frac{\sin X}{X} = \frac{5280}{5284.12}.$$

Expanding $\sin X$ into its trigonometric series and, for an approximation, using only the first two terms of that series, we obtain:

$$1 - \frac{X^2}{3!} = \frac{5280}{5284.12},$$

From this X , or $\frac{\theta}{2}$, is found to be approximately 0.0684 radians. To determine h , we need the following geometric relationship from Figure A1:

$$h = \frac{c}{2} \tan \frac{\theta}{4}.$$

Substituting the appropriate values into this equation, $h = 90.32$ ft, which is the maximum lateral movement one could expect due to thermal expansion.