CEMENTING WELL CASING IN PERMAFROST

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Cementing an oil well is a construction operation. The cement placed in a well is part of a subsurface structure that should last during the life of the well. It should be so placed that it will function effectively for the longest possible time. Every effort must be made therefore to make the original or primary cement job the best possible. When adverse conditions are suspected, it will pay to find out and try to correct the unfavorable ones.

To design a cementing application for oil well casing, there are certain things that can affect the setting time and strength of the cement. The well conditions as they will exist during the job and conditions after the job should be determined or anticipated. The temperature, pressure, water used in mixing cement slurry, type of cement contaminants that could contact the slurry, lost circulation zones, etc, all are factors to be contended with prior to putting a cement slurry into a well.

One of the major factors is temperature; and in the North, this is a big factor in all activities. Not only are the air temperatures low, but the underground temperatures are low (permafrost); and this fact presents many problems in designing a cement system to be used in cementing oilwell casing. Most cement systems that can be used in normal temperature areas will not set or develop strength in extremely cold temperatures. To overcome the low temperatures, new techniques and new cement systems have been developed.

Before placing cement slurries into wells, they have to be mixed. At the present time in the Far North, portable mixers are used in most areas. Some of these are truck-mounted, and others are on skids (skid units). The basic design in all of these includes a mixer and a pump to place the slurry in the well. The mixers are of three types: the jet mixer, the paddle mixer, and the Tornado[2] mixer. The paddle mixer (Figure 1) utilizes an auger to feed the dry cement to a mixing tub where water is metered in and the slurry is paddled to proper consistency. The jet mixer (Figure 2) makes use of the venturi effect, which induces a partial vacuum at the venturi throat. The partial vacuum draws the cement into the fluid stream where turbulence causes mixing both at this point and in the pipe leading away from the mixing "bowl" or venturi throat. Control is dependent on two factors: regulation of the volume of water forced through the jet; and keeping the hopper full of material being

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[1] Dowell of Canada, Dow Chemical of Canada Ltd., Calgary, Alberta.

[2] Dowell Service Mark

mixed. The Tornado mixer (Figure 3) uses a volute of fluid from a high volume pump to mix and disperse the cement into the water. In either case (jet or Tornado mixer), a pump transfers slurry down the hole. As the volume of work increases in the North, the larger truck mounted units will be available. Some of the small units in current use are con structed so that they may be flown to location either by plane or helicopter.

Until 1960, all the cement used in the North was Portland cement. Portland cement, if kept above 40°F, will develop adequate strength. Below 40°F, there is very little reaction to develop strength. The use of Portland cement for cementing casing has been successful when precautions have been taken to make sure enough time is given to allow the cement to develop enough strength before the temperature goes down below 40°F. Portland cement includes normal (construction) Portland, and also hi-early strength Portland cement. In A.P.I. standards and specifications, normal or construction cement is similar to Class C oilwell cement. With the use of accelerators (mostly calcium chloride) and controlled slurry temperature, these Portland cements have been fairly successful in most cases. With regard to the temperature of the slurry, the author's company has developed a formula and charts to assist in controlling the initial slurry temperature.

To ascertain the initial slurry temperature, the specific heat of cement and water is used ignoring the container or, specifically, the mixing tub. This will give an estimate of slurry temperature within a few degrees and will be close enough for practical needs. Based on the standard 46% water ratio, the following formula can be used:

$$T_m = 0.7\ T_w + 0.3\ T_c$$

T_m = Slurry Temperature
T_w = Water Temperature
T_c = Dry Cement Temperature

This is also shown in the graph in Figure 4.

Based on any other percentage of water, the following formula can be used:

$$\text{Percentage of Water } (T_w - T_m) = 0.2(T_m - T_c)$$

Percentage of Water = as Decimal Fraction
T_w = Water Temperature
T_c = Cement Temperature
T_m = Slurry Temperature

$CaCl_2$ will increase the initial slurry temperature 2° to 4°F above the calculated temperature.

These charts have been used since 1963, and have been found to be sufficiently accurate for the practical aspects of cementing in oil wells. If slurry temperatures are in the 60°F range, there has not been usually any problem in obtaining the strength with Portland cement. The technique of placing the cement behind the pipe and following the plug with warm water in the casing has been successful in keeping the cement temperatures up long enough to obtain adequate strength. Also, in some cases, warm fluids have been circulated in the casing until the cement has reached adequate strength. A compressive strength of 500 psi is considered adequate in oil and gas wells.

Beginning in 1956, external heating of cement was investigated in an attempt to obtain better surface cementing jobs. Both chemical and electrical heating were found to be successful, but were not economically feasible. In 1961, high alumina cement systems were introduced (Thorvaldson, 1962). The main attribute of high alumina cements is the fast liberation of the heat of hydration. It is generally agreed that the total heat liberated per unit weight of cement (approximately 100 to 120 calories/gram) is substantially the same for high alumina cement, ordinary Portland cement, and rapid-hardening (hi-early strength) Portland cement. The basic difference between these cements is the production of heat once hydration is underway. When Portland cement is mixed with water, there is usually an immediate but small evolution of heat, followed later by the major release of heat due to the process of normal hydration. High alumina cements do not show the initial evolution of heat, but delays approximately two hours; once started, the liberation of heat proceeds very rapidly. Average values for the maximum rate of heat evolution have been given as follows:

9 calories/gram per hour for High Alumina Cement
3-5 calories/gram per hour for rapid hardening (hi-early) Portland Cement
1.5-3.5 calories/gram per hour for Ordinary Portland Cement

Thus, if high alumina cement is used and prevented from freezing for about two hours, it will generate sufficient heat to obtain adequate strength before the temperature goes down. This is a normal practice of mixing a 60°F slurry and pumping it down the well. With enough slurry volume, there is no need for external (internal in the pipe) heat added to set and obtain adequate strength.

At the present time, our laboratory in Tulsa is doing some research work in developing cement systems for the North Slope of Alaska. Some of their interim work shows the advantages of the use of high alumina cement.

A model was constructed to simulate North Slope conditions as nearly as possible in the laboratory. A diagram of the model is shown in Figure 5. In general, the model consisted of a frozen mass with a simulated wellbore. A pipe was centred in the hole and equipped to circulate fluid through the pipe as desired. Thermocouples were attached at various points in the model to measure temperatures continually. The model was kept in a cold room at 15°F. Neat Cement Fondu (high alumina cement) was tested in the model under the following conditions:

1. Model at 15°F - Temperature recorder on.
2. Mixed Neat Fondu at 15.6 lbs/gal with slurry temperatures at 46°F.
3. Circulated 40°F fluid through the pipe - one pass to simulate the 46°F slurry being placed.
4. Immediately placed the 46°F slurry into the annulus.
5. Continually monitored temperatures at five points illustrated on the model schematic.
6. Let the model return to equilibrium with the cold room temperature after the heat of reaction had peaked and subsided.
7. Recovered the cement column and pipe for inspection.

OBSERVATIONS

1. Pertinent areas in the model did not drop below freezing temperatures until after the heat from the setting reaction had subsided.
2. A reasonable heat of hydration was evident.
3. The ice-cement interface reflected a temperature increase from the reaction; however, it is important to note that the temperature 2 inches into the ice mass from the interface did not ever rise above freezing.
4. The pipe and cement column were firmly locked in the model.
5. When the pipe and cement sheath were recovered from the model, the sheath was hard-set cement throughout the column. A thin outer layer at the cement-ice interface did not appear to be as strong - but was set cement.

The temperature curves obtained during this run are shown in Figure 6. It is important to note that the cement went through a heat of hydration and set. Also, 2 inches into the ice mass, the temperature did not ever rise above freezing.

In conjunction with the model study, it was found that Cement Fondu developed 2,594 psi compressive strength in 16 hours at 40°F. The model study shows the next Fondu remained above 40°F for approximately 15 hours during the test run.

A cement system of Cement Fondu and Wabamum Flyash in a 1:1 volume ratio was also tested and temperature curves are shown in Figure 7. The initial slurry temperature was 40°F. The inner pipe was circulated with 40°F water at a rate of approximately 1 gallon/minute for approximately 8 hours - except for two short periods of stopping to try to determine heat of hydration. Very little heat was detected. As before, the resulting cement had the same appearance as the neat Fondu. The cement was set hard against the pipe with a thin layer of poor cement at the cement-ice interface.

Compressive Strength at 40°F
1:1 Cement Fondu - Wabamum Flyash

8 Hours	16 Hours
518 psi	1,937 psi

Neat Cement Fondu at 40°F

16 Hours	24 Hours
2,594 psi	3,505 psi

The tests made with Cement Fondu (high alumina cement) have shown that, by using neat Cement Fondu and keeping it from freezing in the initial slurry for two to three hours, there is enough rapid heat of hydration to develop adequate strength even though placed in permafrost. Most other cement systems have to use some external form of heat to develop adequate strength.

Another special cement system for use at freezing temperatures and below has been developed and patented (Reference 2). Basically, this system employs a mixture of Portland cement and calcined gypsum. Mixing fluid is water with a freezing point depressant. One such system was checked which did set and develop some compressive strength at 15°F. These systems are probably adaptable to use in permafrost, especially where supercooled drilling fluid is used.

In conclusion, from what has been observed in the cementing of surface casing in the North, Portland cements (especially hi-early strength cement) can be used successfully if precautions are observed and proper techniques are used. Slurry temperature should be maintained in the 60°F range and the cement given some external heat (such as warm water following the plug or circulating warm fluid in casing after placing the cement in the annulus). It is felt, however, that the best cement at present is high alumina cement. This cement will set and gain adequate strength even without any external heat.

REFERENCES

1. Thorvaldson, W. M. Low Temperature Cementing. Canadian Oil and Gas Industries, Nov. 1962.
2. United States Patent 3,179,528: Low Temperature Cementing Composition - Pan American Petroleum Corporation.

APPENDIX "A"

Since presentation of this paper, added data concerning bond strength have become available and are of interest.

Tests were conducted to study the bond strength of the cement to the pipe and the cement to the face of the ice. A test apparatus was designed where the pipe could be cemented and the set cement column then bonded to ice by curing the apparatus in the cold room at 15°F. After curing, the bond strength was determined.

Cement System	Cement to Pipe psi	Cement to Ice psi
Cement Fondu Neat	988	539
50:50 Fondu:Litepoz 3	374	438
Portland Mixture - Anti-freeze	67	43

The shear bonds obtained are relative but in the case of either Fondu system the results compare favorably with those obtained with various Portland systems under conventional conditions.

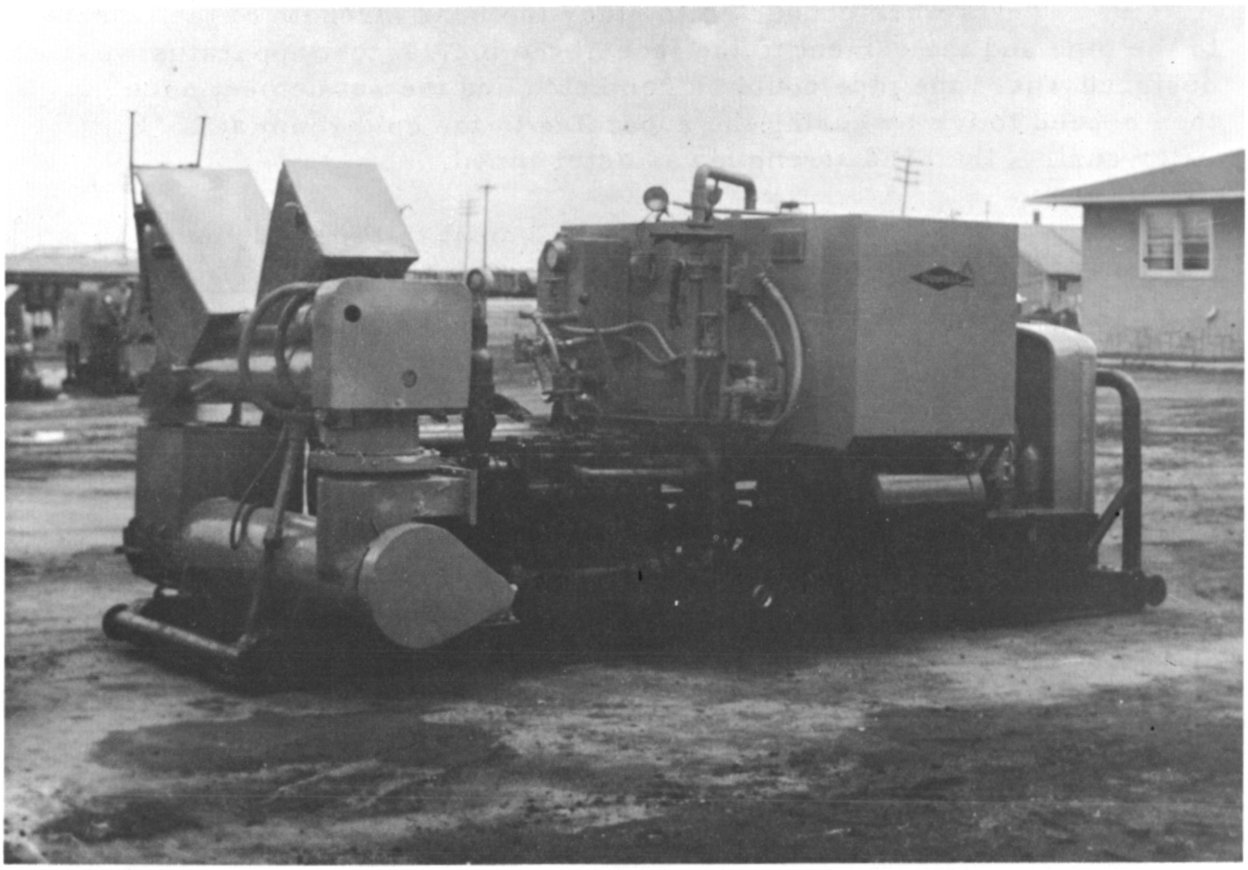


Fig. 1 Paddle mixer.

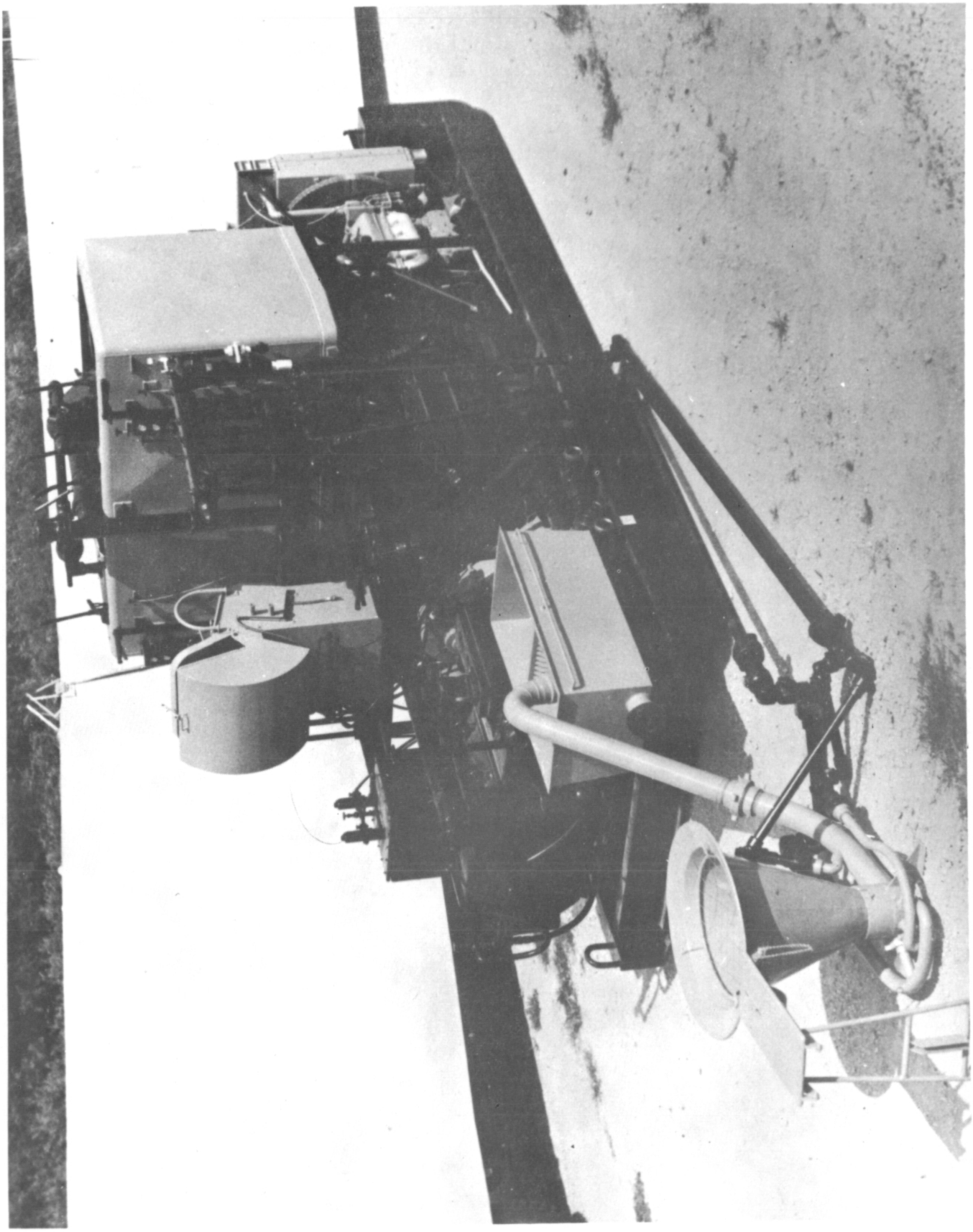


Fig. 2 Jet mixer.

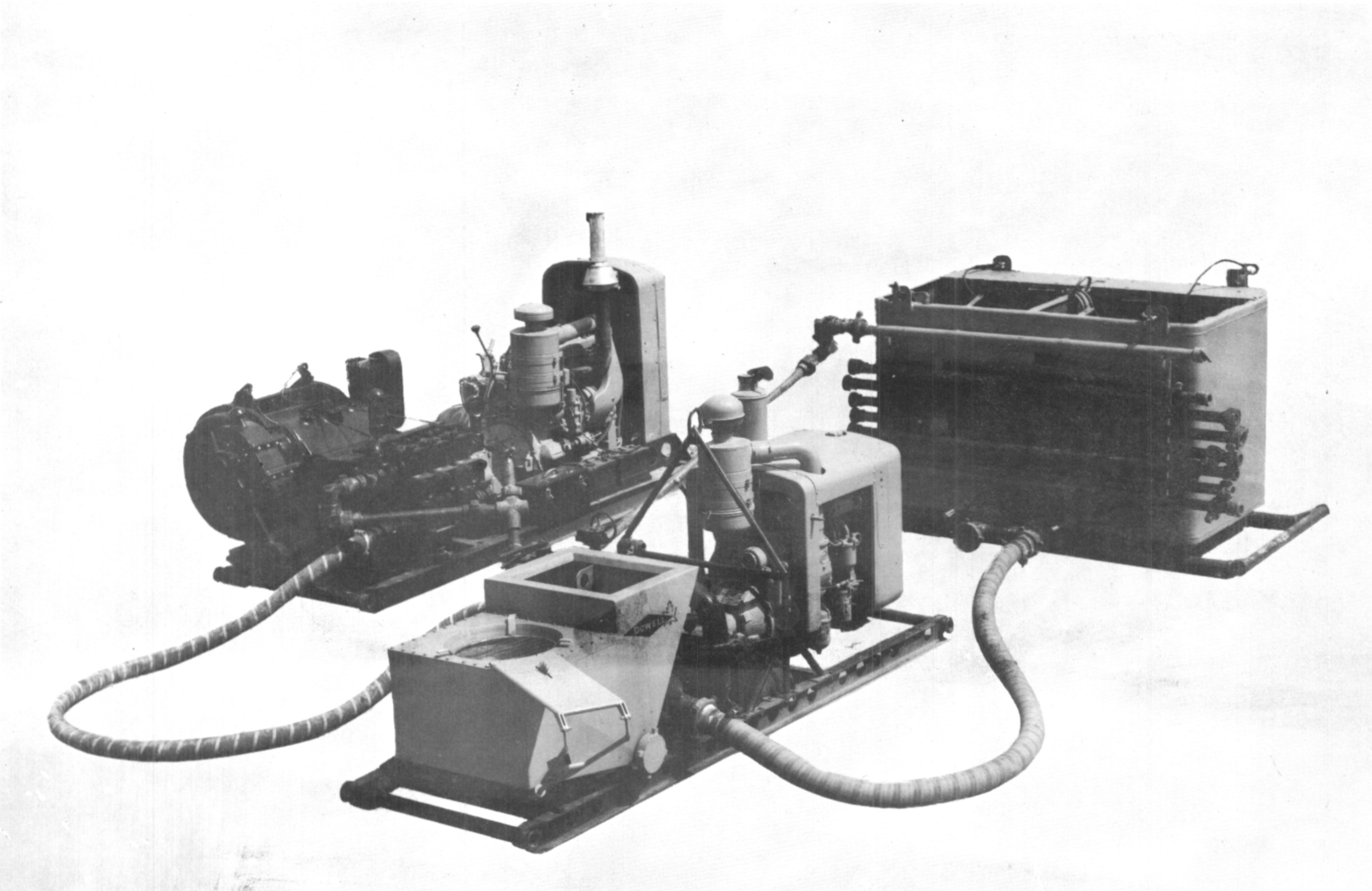


Fig. 3 Cementing unit made up of individual units. This combination uses tornado mixer skid.

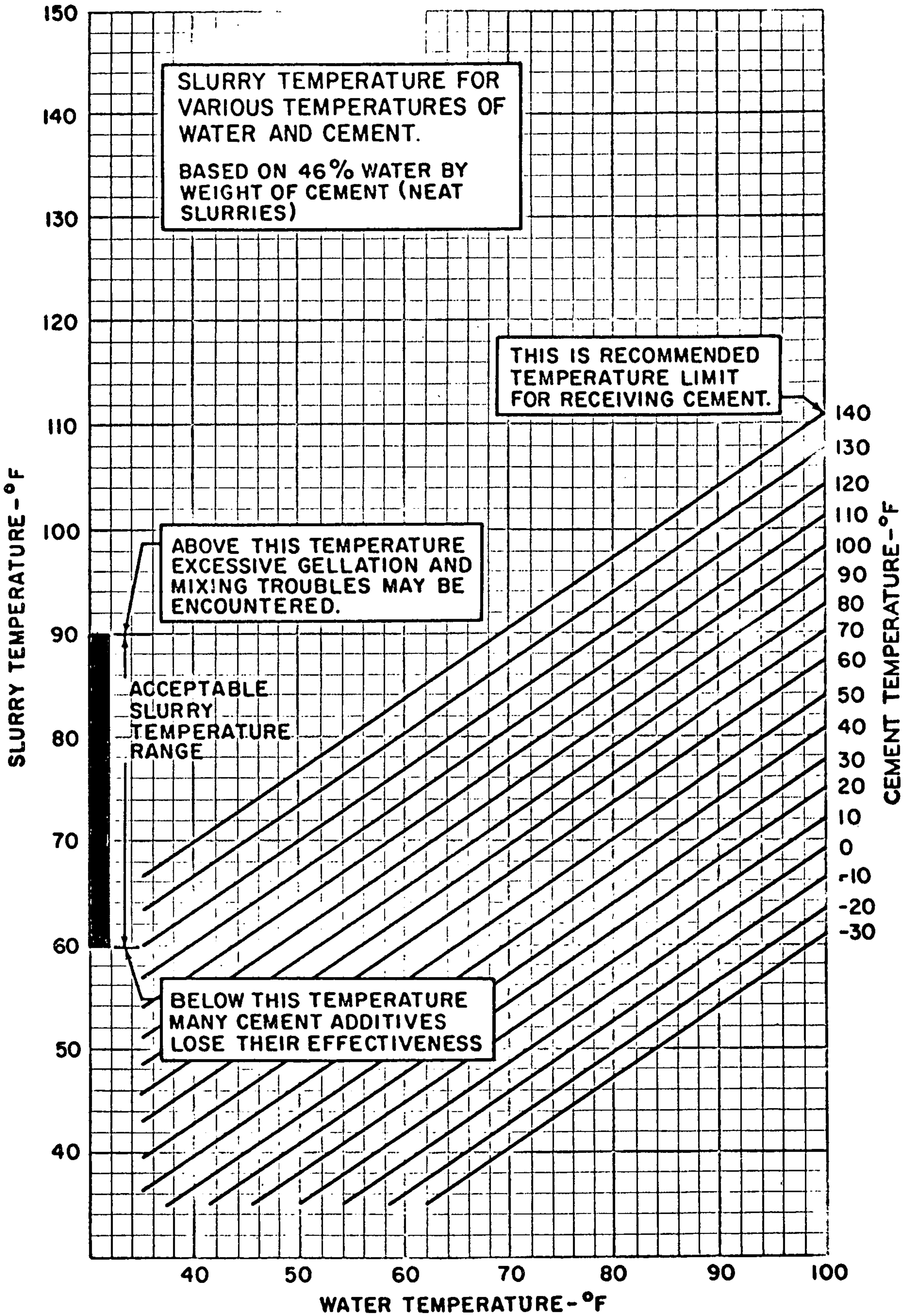


Fig. 4 Graph of water temperature vs. slurry temperature.

1 THERMOCOUPLE PLACED IN THE PERMAFROST 4" FROM CEMENT - PERMAFROST INTERFACE

2 THERMOCOUPLE PLACED IN THE PERMAFROST 2" FROM CEMENT - PERMAFROST INTERFACE

3 THERMOCOUPLE AT CEMENT - PERMAFROST INTERFACE

4 THERMOCOUPLE IN CENTER OF CEMENT SHEATH

5 THERMOCOUPLE AT CEMENT - PIPE INTERFACE

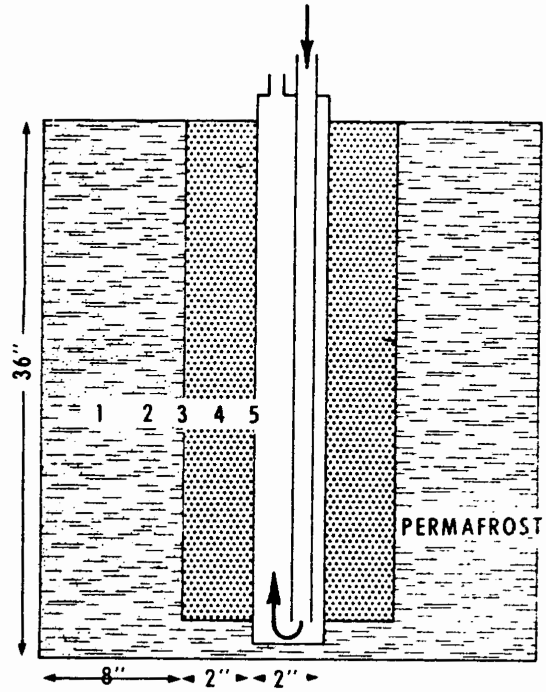
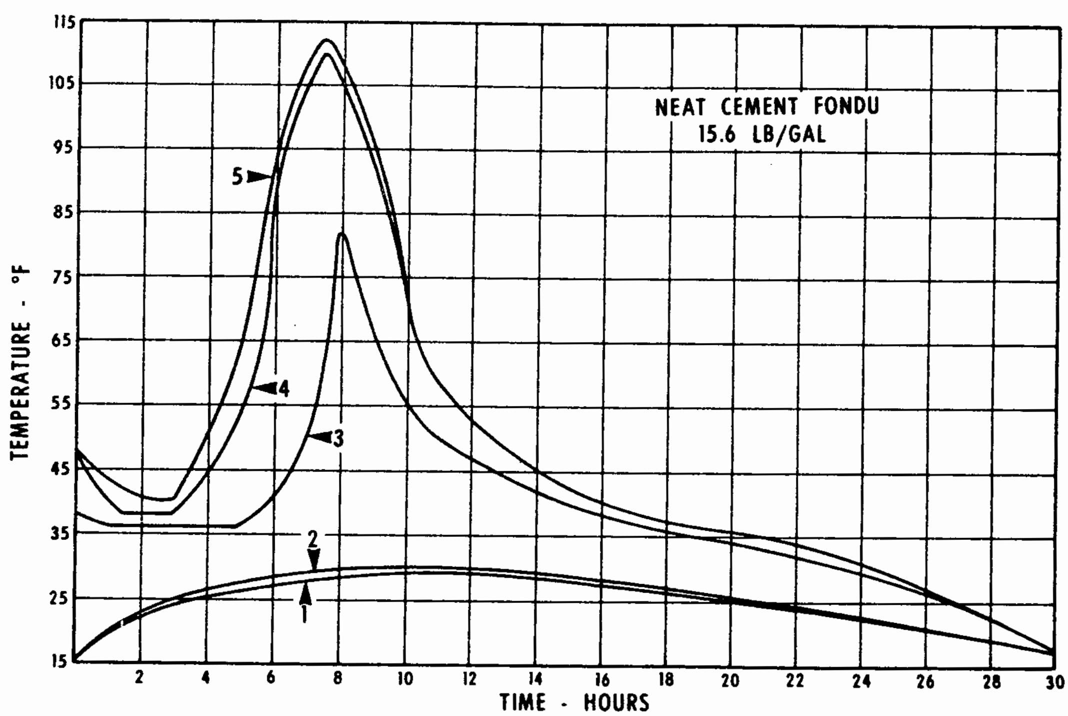
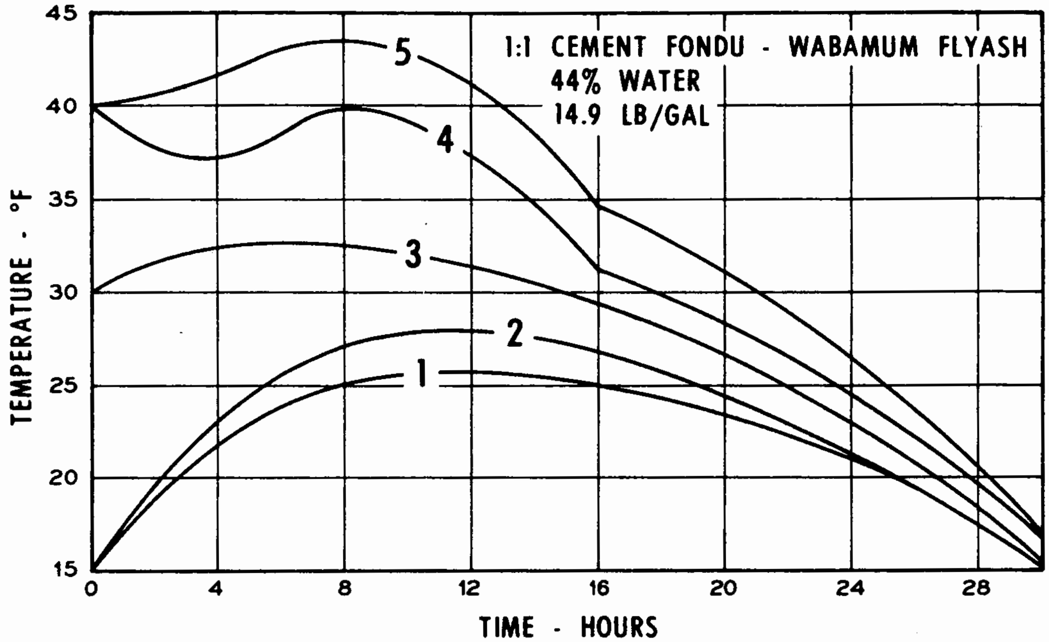


Fig. 5 Model for testing Neat Cement Fondu in permafrost conditions.



1. THERMOCOUPLE PLACED IN THE PERMAFROST 4" FROM CEMENT - PERMAFROST INTERFACE
2. THERMOCOUPLE PLACED IN THE PERMAFROST 2" FROM CEMENT - PERMAFROST INTERFACE
3. THERMOCOUPLE AT CEMENT - PERMAFROST INTERFACE
4. THERMOCOUPLE IN CENTER OF CEMENT SHEATH
5. THERMOCOUPLE AT CEMENT - PIPE INTERFACE

Fig. 6 Time-temperature test curves for setting of Neat Cement Fondu in permafrost conditions.



1. THERMOCOUPLE PLACED IN THE PERMAFROST 4" FROM CEMENT - PERMAFROST INTERFACE
2. THERMOCOUPLE PLACED IN THE PERMAFROST 2" FROM CEMENT - PERMAFROST INTERFACE
3. THERMOCOUPLE AT CEMENT - PERMAFROST INTERFACE
4. THERMOCOUPLE IN CENTER OF CEMENT SHEATH
5. THERMOCOUPLE AT CEMENT - PIPE INTERFACE

Fig. 7 Time-temperature test curves for setting of 1:1 Cement Fondu-Wabumum Flyash in permafrost conditions.

Discussion

Mr. P. Washchyshyn asked how high alumina cement compares in compressive strength and other properties with normal Portland cement for construction purposes in the North. The author replied that it is used considerably in northern construction and it develops a very high compressive strength for concrete. It is used to repair runways because it develops high strength rapidly.

Mr. K. Hinchey remarked that he had seen mention of the experimental use of an insulated pipe being placed in the hole to protect the surrounding permafrost from being thawed by the heat from oil coming to the surface at a temperature of 200°F. He asked whether the author was aware of this. Mr. Cameron replied that there has been little oil production in the North to the present time but there have been investigations with running an extra string and using heated fluid in a suspended pipe in a gas well to keep up production temperatures. For oil production in the North, it would be a matter of reversing the procedure and using a supercooled coolant to cool the upper part of the hole. Salt water or some fluid containing an inhibitor against freezing could be circulated in the hole.