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ATTACHMENT 2

Evaluation of GTL #2 and Crude Oil Blends For Yield Stress Values

A REPORT BY WESTPORT TEHCNOLOGY CENTER

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TECHNOLOGY CENTER INTERNATIONAL

RT-01-038

November 2001

Evaluation of GTL #2 and Crude Oil Blends For Yield Stress Values

Final Report

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Introduction

The gel strength of various GTL (gas to liquid samples) and North Slope crude oil blends were determined by the rotating vane method. The tests for determining the yield stress, or yield stress value, of the cooled crude oil blends, were performed following Westport's Standard Laboratory Procedure (SLP) 307, "Crude Oil Yield Stress value Determination by Vane Viscometry". This determination was made with Brookfield rotary viscometers and vane spindles, which extend horizontally through a sample, minimizing the impact of slippage at the spindle wall. This method determines the minimum amount of torque necessary to initiate oil movement at low shear, and subsequent gel breakdown after initiation of flow. These data can be directly used in modeling of crude oil behavior in pipelines, during start-up conditions.

Test Results

Twenty-four test samples were prepared by weight for testing, eight each at the three ratios listed below:

(a). 100% Light Hydrocarbon GTL #2
(b). 25% Light Hydrocarbon GTL #2 + 75% TAPS Mix Crude at PS-1
(c). 20% Light Hydrocarbon GTL #2 + 80% TAPS Mix Crude at PS-1

The client supplied the light hydrocarbon GTL samples. The crude oil sample was supplied by the Alyeska Pipeline Service Company, taken from the flowing TAPS mixed stream at Pump Station 1. All blend mixes were carried out by weight to weight measurements.

Samples were tested at selected temperatures as the crude oil blends were cold ramped from 90°F to -20°F over a twenty-one day period. The maximum recorded torque obtained during vane rotation at a constant speed of 0.01 rpm was converted into a yield stress value. The summary of vane test results is presented in Table 1 and Figure 1.

Initially, test temperatures were set at 20°F, 0°F and –20°F. However, simple bottle testing of the GTL #2 sample indicated possible gel strength onset at earlier temperatures. Therefore, tests were performed on the 100% GTL at 27°F and a yield stress of 171 dynes/sqcm were recorded.

At a temperature of 20°F the GTL #2 sample had reached it's pour point value and gel strength was beyond the limits of the RV viscometer. Averaged yield stress values of 2.91 dynes/sqcm for the 3:1 ratio blend and 1.13 dynes/sqcm for the 4:1 ratio blend were measured. The 100% GTL produces high gel strength, but when blended with TAPS mix crude a significant reduction occurred. It is also evident that ratio blending also contributes to lower yield stress values.

At a temperature of 0°F the 3:1 ratio blend with TAPS mix crude produced an average yield stress value of 694 dynes/sqcm. The 4:1 ratio blend with TAPS mix crude produced an average yield stress value of 389 dynes/sqcm. This again supports that ratio blending may be effective in lowering the ultimate yield stress values of GTL/crude oil blends.

The effect on yield stress values from ratio blending was not apparent in prior testing performed with the GTL #1 sample. At present time, testing has not been performed with alternative crude oil samples to determine if the effect of ratio blending is reproducible with varying crude composition.

All testing performed at a temperature of –20°F produced yield stress values beyond the measurable limits of the Vane test equipment, or values greater than 1589 dynes/sqcm.

Table 1: Yield Stress by Vane Viscometer

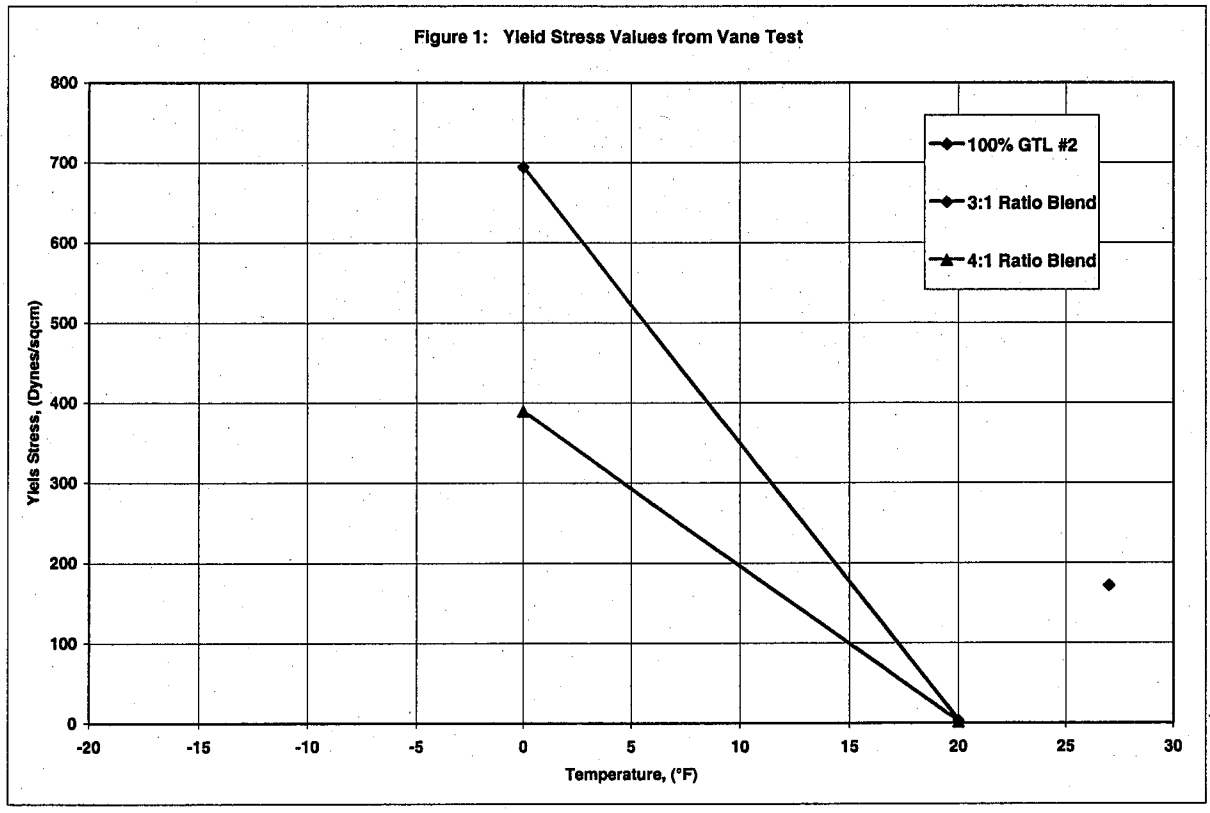
Test Sample (ID #)	Brookfield Viscometer Model	Sample Temperature (°F)	Maximum Torque Response (% full scale)	Yield Point Torque (dyne-cm)	Yield Stress (dynes/sqcm)
GTL-01	RV	27	failed	-	-
GTL-02	RV	27	86.3	6202	171
GTL-03	RV	20	>100	>7187	>199
GTL-04	RV	0	>100	>7187	-
GTL-05	HB	0	>100	>57496	>1589
GTL-06	HB	0	>100	>57496	>1589
GTL-07	HB	-20	>100	>57496	>1589
GTL-08	HB	-20	>100	>57496	>1589
3:1-01	RV	20	1.5	108	2.98
3:1-02	RV	20	1.3	93.4	2.58
3:1-03	RV	20	1.6	115	3.18
3:1-04	LV	0	>100	>674	-
3:1-05	HB	0	41.3	23746	656
3:1-06	HB	0	46.1	26506	732
3:1-07	HB	-20	>100	>57496	>1589
3:1-08	HB	-20	>100	>57496	>1589
4:1-01	RV	20	0.4	28.7	0.79
4:1-02	RV	20	0.9	64.7	1.79
4:1-03	RV	20	0.4	28.7	0.79
4:1-04	LV	0	>100	>674	-
4:1-05	RV	0	>100	>7187	-
4:1-06	HB	0	21.9	12592	348
4:1-07	HB	0	27.1	15581	431
4:1-08	HB	-20	>100	>57496	>1589

Temperature (°F)	Yield Stress (average) (dynes/sqcm)
100% GTL #2	
27	171
20	>199
0	>1589
-20	>1589

3:1 Ratio Blend	
20	2.91
0	694
-20	>1589

4:1 Ratio Blend	
20	1.13
0	389
-20	>1589

Figure 1: Yield Stress Values from Vane Test



SECTION 1

Yield Stress versus Elapsed Time For GTL #2 & TAPS Crude Oil Blends

Summary of Test Method

Westport's SLP-307 consists of determining the yield stress value of a crude oil by measuring the torque on a spindle, using a Brookfield viscometer, rotating at 0.01 rpm in the material. The spindle to be used consists of four rectangular vanes dimensioned (0.75"w x 2.25"h) and oriented at 90 degree increments around the central axis. The sample cup is dimensioned (1.5" id x 4.0"h). Vertical orientation of vanes within the sample cup is dimensioned (1.00" from top and 0.75" from bottom).

The crude oil blends were initially heated to 150°F to destroy all temperature and shear histories and then cooled to 100°F at which stress value they were loaded into the vane closed-cup apparatus. The closed-cup apparatus holds the vanes rigidly during cooling and aging and prevents loss of light ends through evaporation. After loading into the cup apparatus the samples were cooled in an environmental chamber at a controlled rate to below 0°F. The cooling rate mimics the expected rate of cooling of the Trans-Alaska pipeline oil in the case of shut-in.

Samples were withdrawn from the environmental chamber at five test temperatures (approximately 60, 40, 20, 9 and 0°F) and transferred to a refrigerated circulator that maintains the sample at test temperature. The spindle was attached to the Brookfield viscometer (LV, RV or HB) before the spindle clamping mechanism was released. The clamping mechanism was released and the viscometer was started at 0.01 rpm and torque as a function of time was measured, until a maximum reading was obtained. The maximum torque (dyne-cm) obtained is divided by a vane parameter constant K to obtain the yield stress (dynes/sqcm). The constant K is calculated based on the dimensions of the vanes. (K=36.19 cm^3, for a Vane with D=0.75 inch (1.905 cm) and H=2.25 inch (5.715 cm). For further detailed information Westport's SLP-307 is attached in Appendix B.

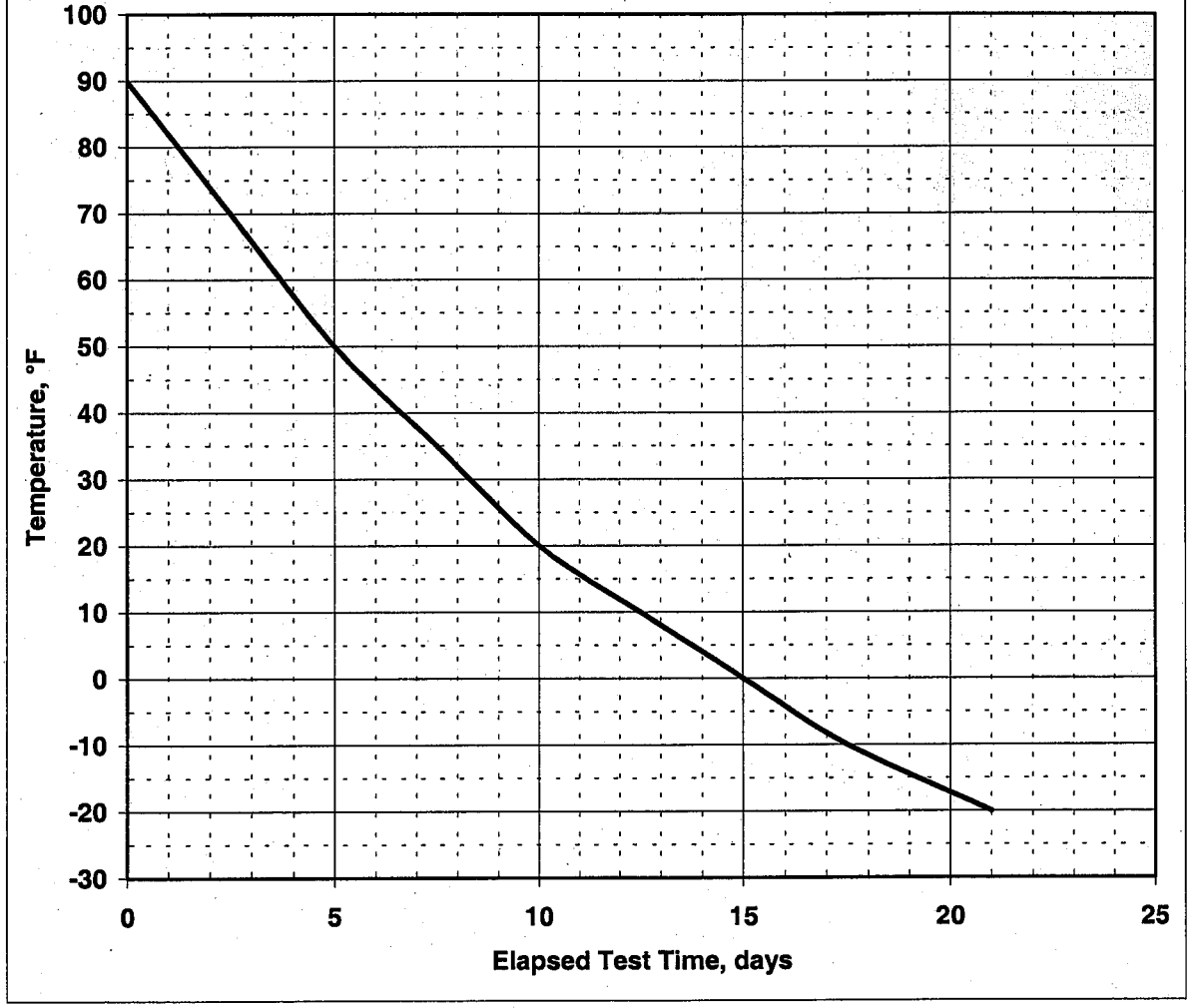
Temperature Ramping Profile

The temperature decay curve used for test sample preparation was taken from Trans-Alaska Pipeline cold restart data supplied by the Alyeska Pipeline Service Company. Based on this curve, selective temperatures were entered into the program menu of the environmental cooling chamber, a cryogenic chamber cooled by liquid Nitrogen vapor. Temperatures are recorded on strip chart display with digital inscriptions at 12-hour intervals. The programmed temperature ramp is presented in Table 2 and Figure 2.

TABLE 2, TEST TEMPERATURE PROFILE
VANE AND ROTARY VISCOMETRY

Environmental Chamber Temperature Ramp Program				
Step #	**Days**	**Hours**	**Temp °F**	**Temp °C**
0	0	0	90	32.2
1	2.5	60	70	21.1
2	5	120	50	10.0
3	7.5	180	35	1.7
4	10	240	20	-6.7
5	12.5	300	10	-12.2
6	15	360	0	-17.8
7	17.5	420	-10	-23.3
8	21	504	-20	-28.9
9	Hold	576	-20	-28.9

Figure 2: Test Temperature Profile



DETERMINATION OF YIELD STRESS VALUE

Figures 3 through 25 on the following pages present torque buildup versus elapsed test time. The yield stress value is determined from the maximum torque response, usually followed by a decline indicating any gel structure present was broken by the applied stress and degrades under continued shearing. In most tests, several minutes of "no torque" response at test initiation are recorded; this response is associated with the time for the 'S'-hook connections to "tighten" before movement, or stress, is applied to the vane shaft. One test sample (GTL-01) was not recorded during testing due to data acquisition failure. Numerical data for the remaining twenty-three tests are presented in Appendix A.

100% Light Hydrocarbon GTL #2

Figure 3: Test Sample GTL-02

Figure 3 presents torque response (dyne-cm) versus elapsed test time at a test temperature of 27°F. The test was performed on the Brookfield RV viscometer. A maximum torque of 6202 dyne-cm was recorded giving a yield stress value of 171 dynes/sqcm.

Figure 4: Test Sample GTL-03

Figure 4 presents torque (dyne-cm) versus elapsed test time at a test temperature of 20°F. The test was performed on the Brookfield RV viscometer. A maximum torque limit of the RV viscometer was reached (7187 dyne-cm); therefore the yield stress value was greater than 199 dynes/sqcm. The HB viscometer was under service warranty calibration and unavailable for use at the time of this test.

Figure 5: Test Sample GTL-04

Figure 5 presents torque (dyne-cm) versus elapsed test time at a test temperature of 0°F. The test was performed on the Brookfield RV viscometer. A maximum torque limit of the RV viscometer was reached (7187 dyne-cm); therefore the yield stress value was greater than 199 dynes/sqcm. A second sample was tested on the HB viscometer.

Figure 6: Test Sample GTL-05

Figure 6 presents torque (dyne-cm) versus elapsed test time at a test temperature of 0°F. The test was performed on the Brookfield HB viscometer. A maximum torque limit of the HB viscometer was reached (57496 dyne-cm); therefore the yield stress value was greater than 1589 dynes/sqcm. The HB viscometer has the highest rated spring torque available for this testing.

Figure 7: Test Sample GTL-06

Figure 7 presents torque response (dyne-cm) versus elapsed test time at a test temperature of 0°F. The test was performed on the Brookfield HB viscometer as a check for repeatability. A maximum torque limit of the HB viscometer was reached (57496 dyne-cm); therefore the yield stress value was greater than 1589 dynes/sqcm. The HB viscometer has the highest rated spring torque available for this testing.

Figure 8: Test Sample GTL-07

Figure 8 presents torque (dyne-cm) versus elapsed test time at a test temperature of -20°F. The test was performed on the Brookfield HB viscometer. A maximum torque limit of the HB viscometer was reached (57496 dyne-cm); therefore the yield stress value was greater than 1589 dynes/sqcm. The HB viscometer has the highest rated spring torque available for this testing.

Figure 9: Test Sample GTL-08

Figure 9 presents torque (dyne-cm) versus elapsed test time at a test temperature of -20°F. The test was performed on the Brookfield HB viscometer as a check for repeatability. A maximum torque limit of the HB viscometer was reached (57496 dyne-cm); therefore the yield stress value was greater than 1589 dynes/sqcm. The HB viscometer has the highest rated spring torque available for this testing.

3:1 Ratio Blend (25% GTL #2 + 75% TAPS Crude Oil at PS-1)

Figure 10: Test Sample 3:1 - 01

Figure 10 presents torque (dyne-cm) versus elapsed test time at a test temperature of 20°F. The test was performed on the Brookfield RV viscometer. A maximum torque of 108 dyne-cm was recorded giving a yield stress value of 2.98 dynes/sqcm.

Figure 11: Test Sample 3:1 - 02

Figure 11 presents torque (dyne-cm) versus elapsed test time at a test temperature of 20°F. The test was performed on the Brookfield RV viscometer as a check for repeatability. A maximum torque of 93.4 dyne-cm was recorded giving a yield stress value of 2.58 dynes/sqcm.

Figure 12: Test Sample 3:1 - 03

Figure 12 presents torque (dyne-cm) versus elapsed test time at a test temperature of 20°F. The test was performed on the Brookfield RV viscometer as a check for repeatability. A maximum torque of 115 dyne-cm was recorded giving a yield stress value of 3.18 dynes/sqcm.

Figure 13: Test Sample 3:1 - 04

Figure 13 presents torque (dyne-cm) versus elapsed test time at a test temperature of 0°F. The test was performed on the Brookfield LV viscometer. A maximum torque limit of the LV viscometer was reached (674 dyne-cm); therefore the yield stress value was greater than 18.6 dynes/sqcm. A second sample was tested on the HB viscometer.

Figure 14: Test Sample 3:1 - 05

Figure 14 presents torque (dyne-cm) versus elapsed test time at a test temperature of 0°F. The test was performed on the Brookfield HB viscometer. A maximum torque of 23,746 dyne-cm was recorded giving a yield stress value of 656 dynes/sqcm.

Figure 15: Test Sample 3:1 - 06

Figure 14 presents torque (dyne-cm) versus elapsed test time at a test temperature of 0°F. The test was performed on the Brookfield HB viscometer as a check for repeatability. A maximum torque of 26,506 dyne-cm was recorded giving a yield stress value of 732 dynes/sqcm.

Figure 16: Test Sample 3:1 - 07

Figure 16 presents torque (dyne-cm) versus elapsed test time at a test temperature of -20°F. The test was performed on the Brookfield HB viscometer. A maximum torque limit of the HB viscometer was reached (57496 dyne-cm); therefore the yield stress value was greater than 1589 dynes/sqcm. The HB viscometer has the highest rated spring torque available for this testing.

Figure 17: Test Sample 3:1 - 08

Figure 17 presents torque (dyne-cm) versus elapsed test time at a test temperature of -20°F. The test was performed on the Brookfield HB viscometer as a check for repeatability. A maximum torque limit of the HB viscometer was reached (57496 dyne-cm); therefore the yield stress value was greater than 1589 dynes/sqcm. The HB viscometer has the highest rated spring torque available for this testing.

4:1 Ratio Blend (20% GTL #2 + 80% TAPS Crude Oil at PS-1)

Figure 18: Test Sample 4:1 - 01

Figure 18 presents torque (dyne-cm) versus elapsed test time at a test temperature of 20°F. The test was performed on the Brookfield RV viscometer. A maximum torque of 28.7 dyne-cm was recorded giving a yield stress value of 0.79 dynes/sqcm.

Figure 19: Test Sample 4:1 - 02

Figure 19 presents torque (dyne-cm) versus elapsed test time at a test temperature of 20°F. The test was performed on the Brookfield RV viscometer as a check for repeatability. A maximum torque of 64.7 dyne-cm was recorded giving a yield stress value of 1.79 dynes/sqcm. The variance between 4:1-01 and 4:1-02 was greater than 15%, therefore a third sample was tested.

Figure 20: Test Sample 4:1 - 03

Figure 20 presents torque (dyne-cm) versus elapsed test time at a test temperature of 20°F. The test was performed on the Brookfield RV viscometer as a check for repeatability. A maximum torque of 28.7 dyne-cm was recorded giving a yield stress value of 0.79 dynes/sqcm.

Figure 21: Test Sample 4:1 – 04

Figure 21 presents torque (dyne-cm) versus elapsed test time at a test temperature of 0°F. The test was performed on the Brookfield LV viscometer. A maximum torque limit of the LV viscometer was

reached (674 dyne-cm); therefore the yield stress value was greater than 18.6 dynes/sqcm. A second sample was tested on the RV viscometer.

Figure 22: Test Sample 4:1 – 05

Figure 22 presents torque (dyne-cm) versus elapsed test time at a test temperature of 0°F. The test was performed on the Brookfield RV viscometer. A maximum torque limit of the RV viscometer was reached (7187 dyne-cm); therefore the yield stress value was greater than 199 dynes/sqcm. A third sample was tested on the HB viscometer.

Figure 23: Test Sample 4:1 – 06

Figure 23 presents torque (dyne-cm) versus elapsed test time at a test temperature of 0°F. The test was performed on the Brookfield HB viscometer. A maximum torque of 12592 dyne-cm was recorded giving a yield stress value of 348 dynes/sqcm.

Figure 24: Test Sample 4:1 – 07

Figure 24 presents torque (dyne-cm) versus elapsed test time at a test temperature of 0°F. The test was performed on the Brookfield HB viscometer as a check for repeatability. A maximum torque of 15581 dyne-cm was recorded giving a yield stress value of 431 dynes/sqcm.

Figure 25: Test Sample 4:1 – 08

Figure 25 presents torque (dyne-cm) versus elapsed test time at a test temperature of -20°F. The test was performed on the Brookfield HB viscometer. A maximum torque limit of the HB viscometer was reached (57496 dyne-cm); therefore the yield stress value was greater than 1589 dynes/sqcm. The HB viscometer has the highest rated spring torque available for this testing.

Figure 3: Sample GTL-02 at 27°F RV Viscometer

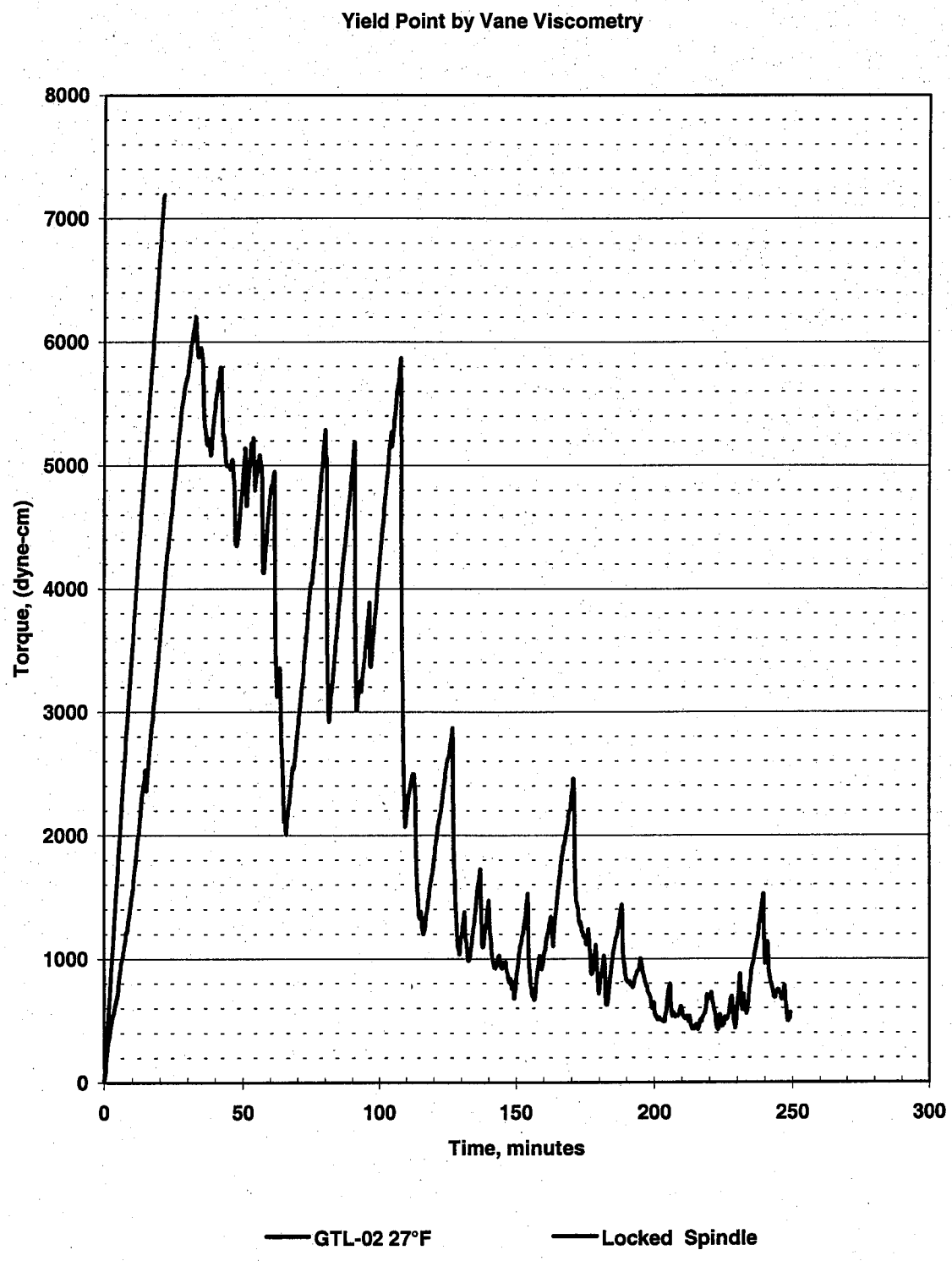


Figure 4: Sample GTL-03 at 20°F RV Viscometer

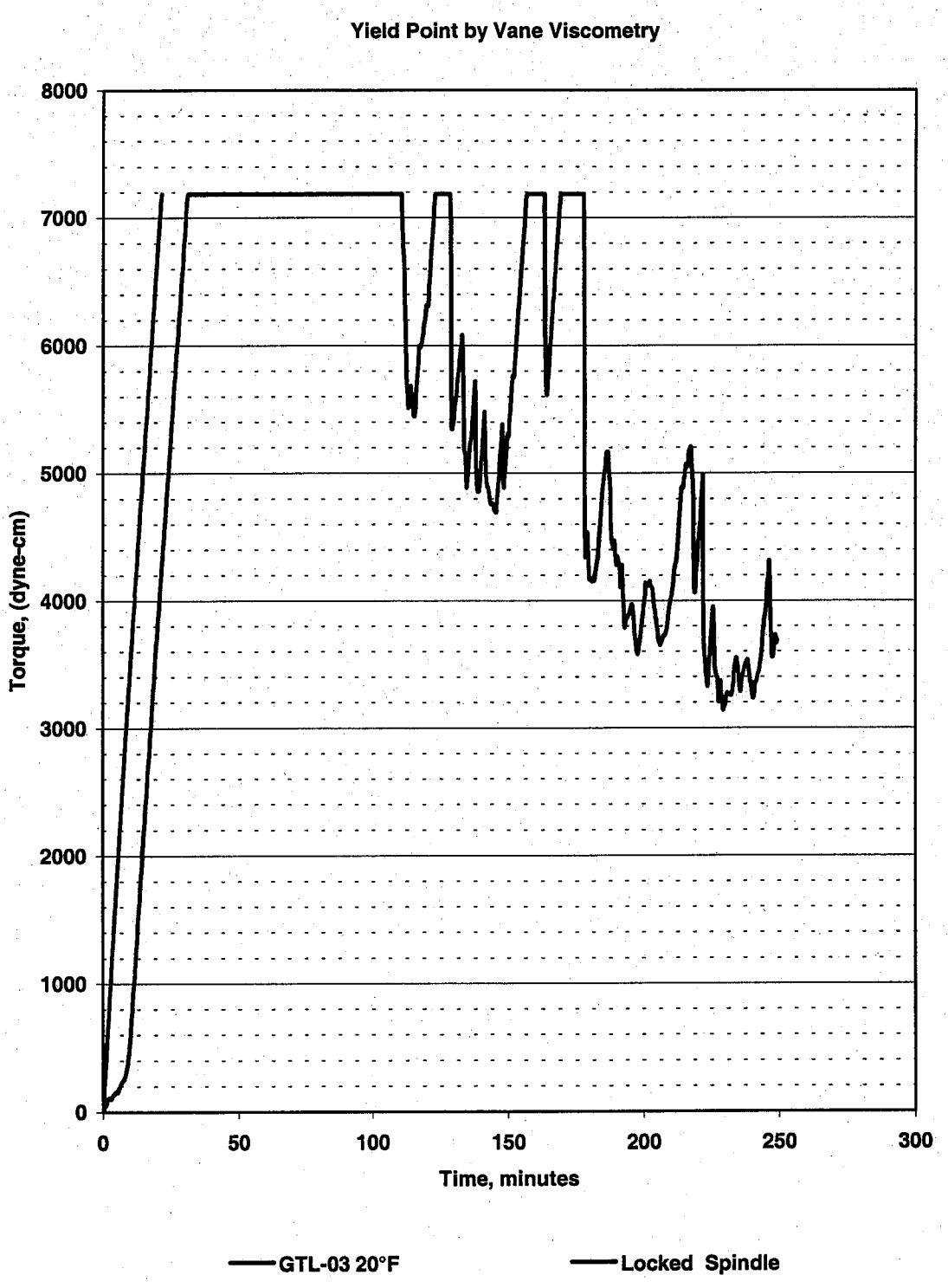


Figure 5: Sample GTL-04 at 0°F RV Viscometer

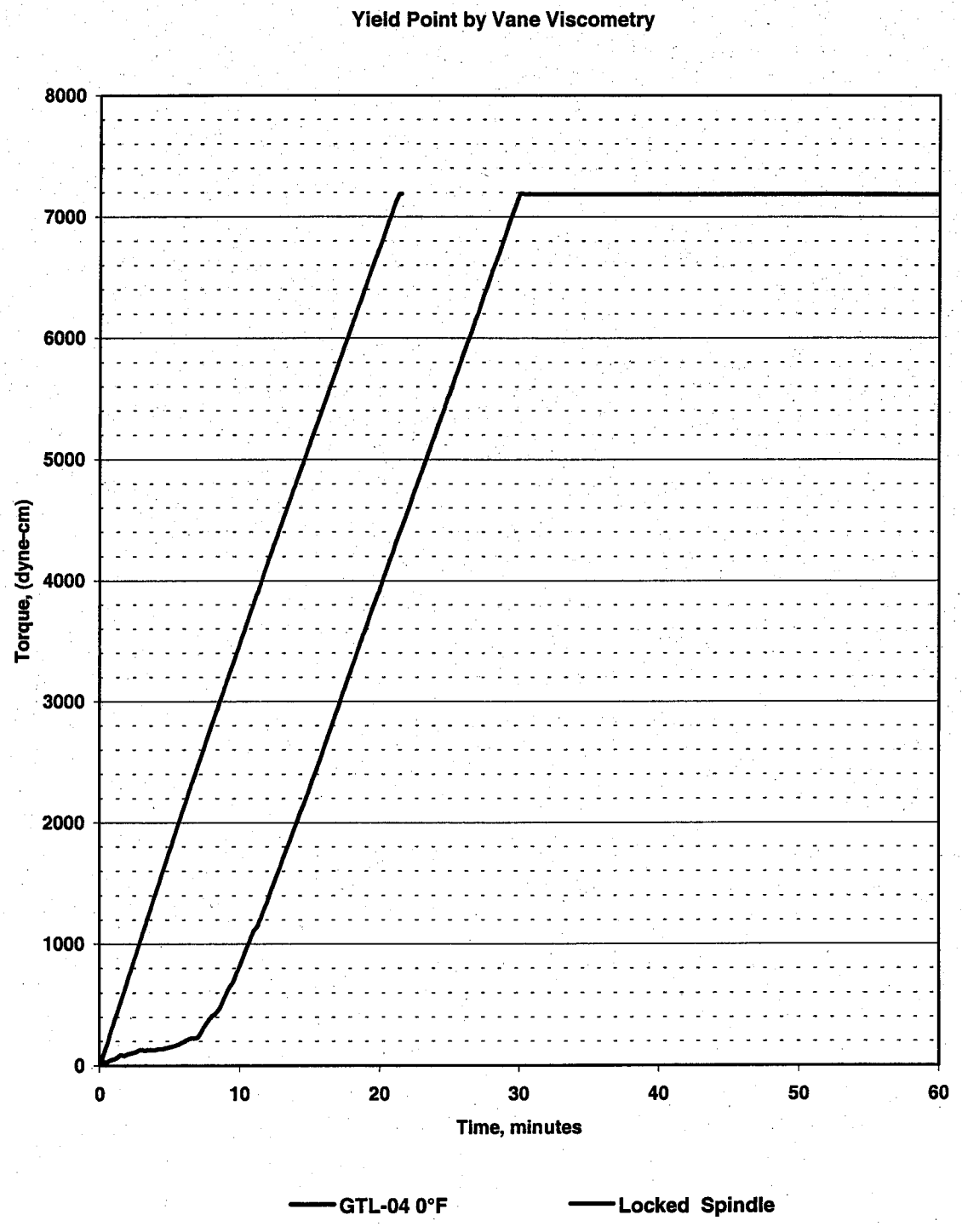


Figure 6: Sample GTL-05 at 0°F HB Viscometer

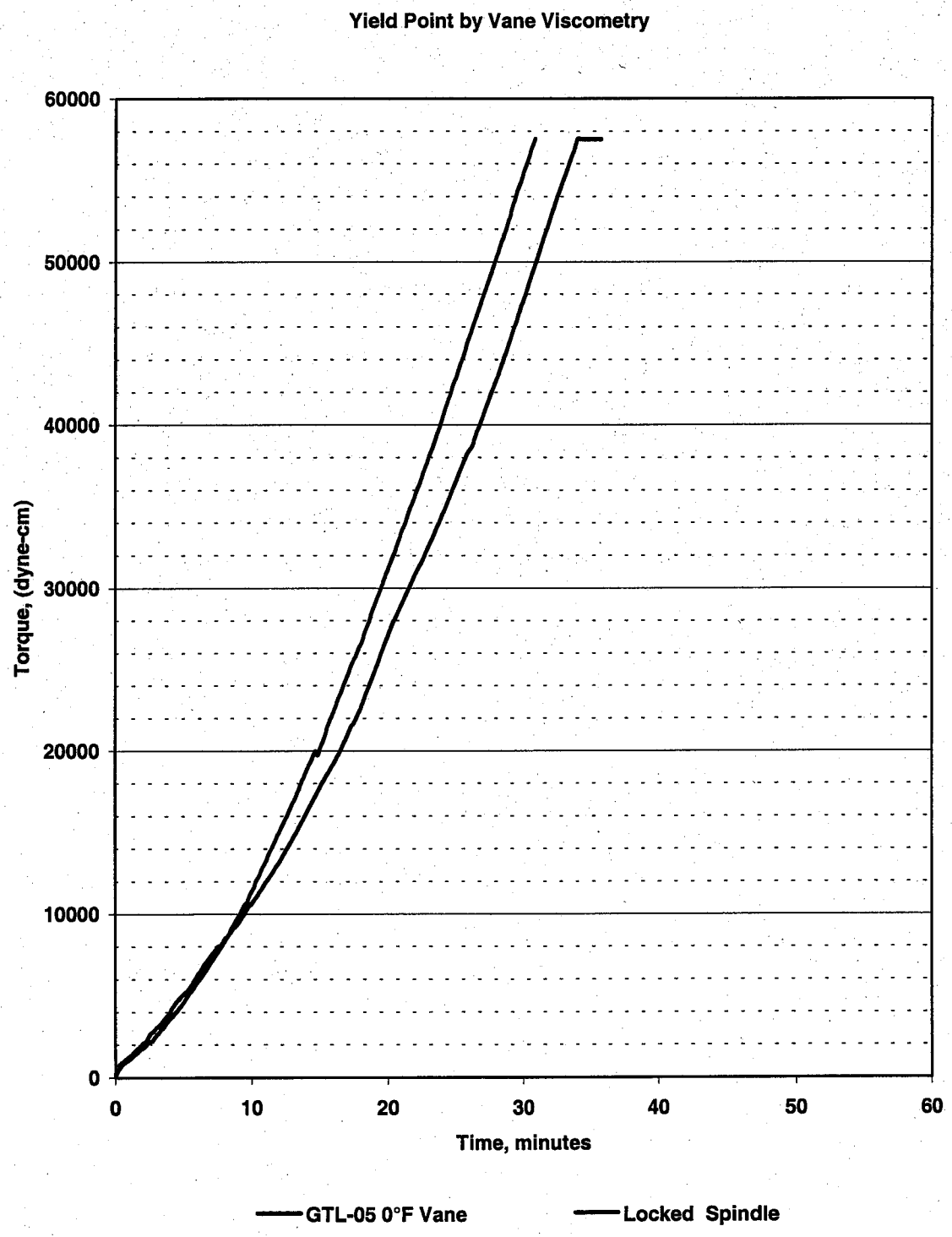


Figure 7: Sample GTL-06 at 0°F HB Viscometer

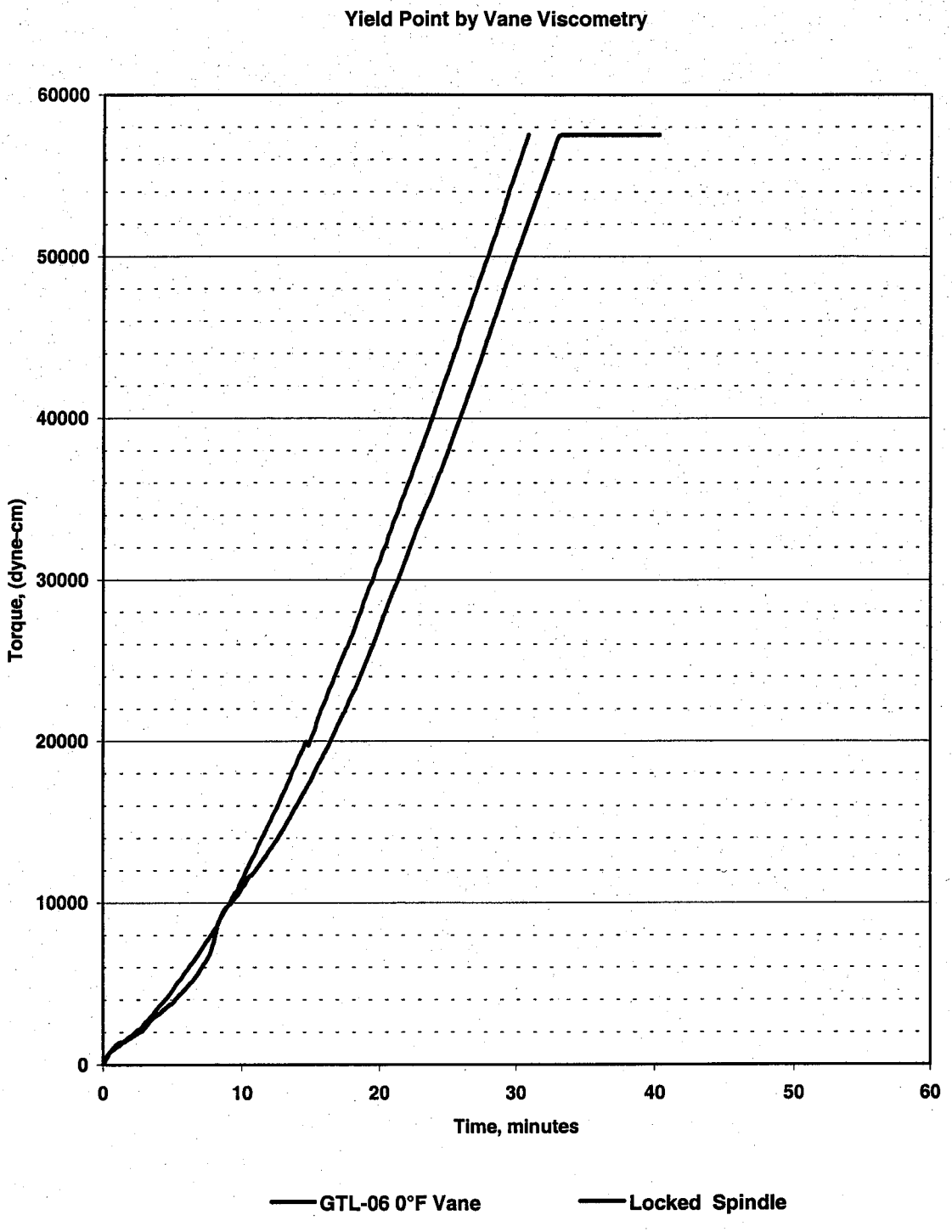


Figure 8: Sample GTL-07 at -20°F HB Viscometer

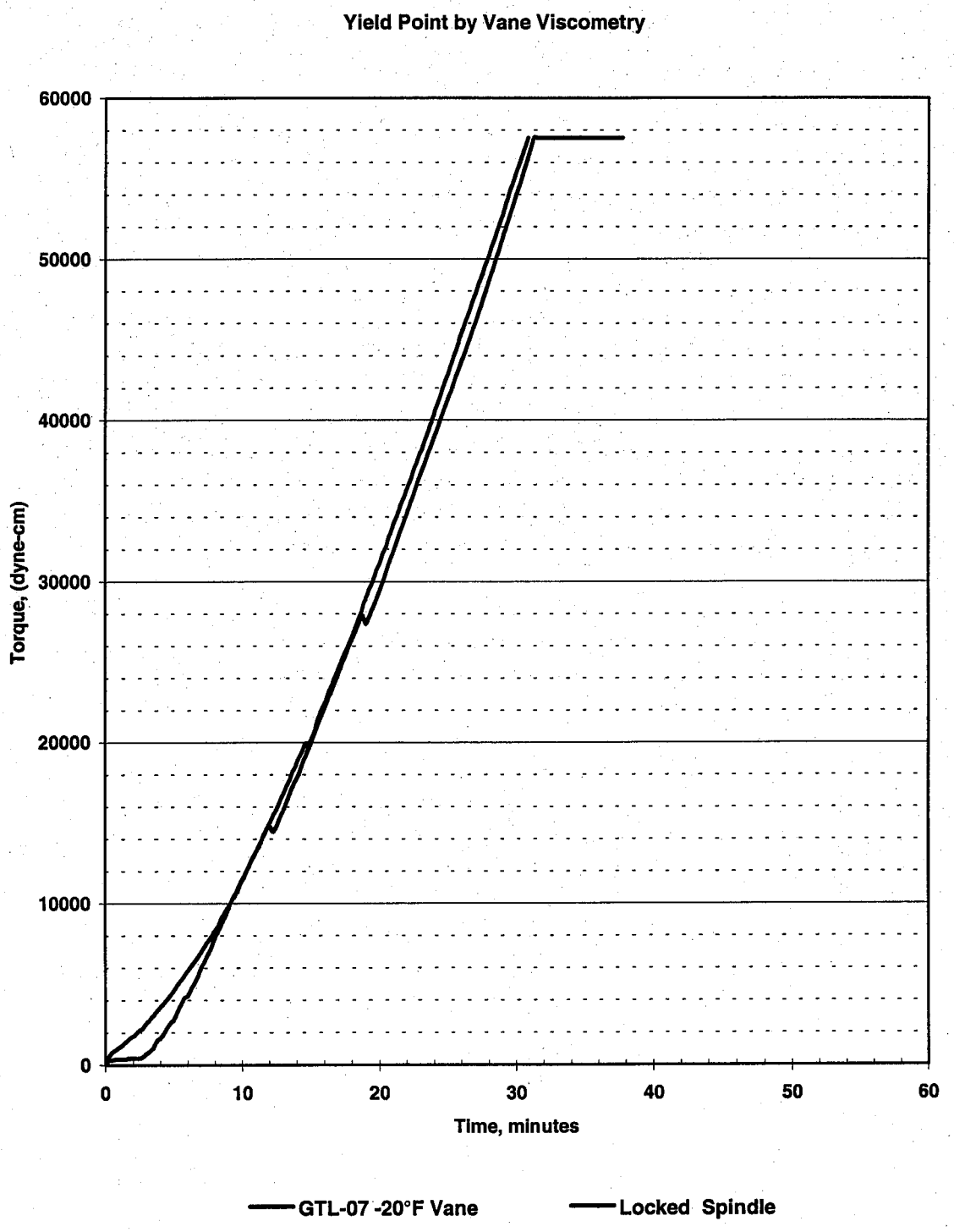


Figure 9: Sample GTL-08 at -20°F HB Viscometer

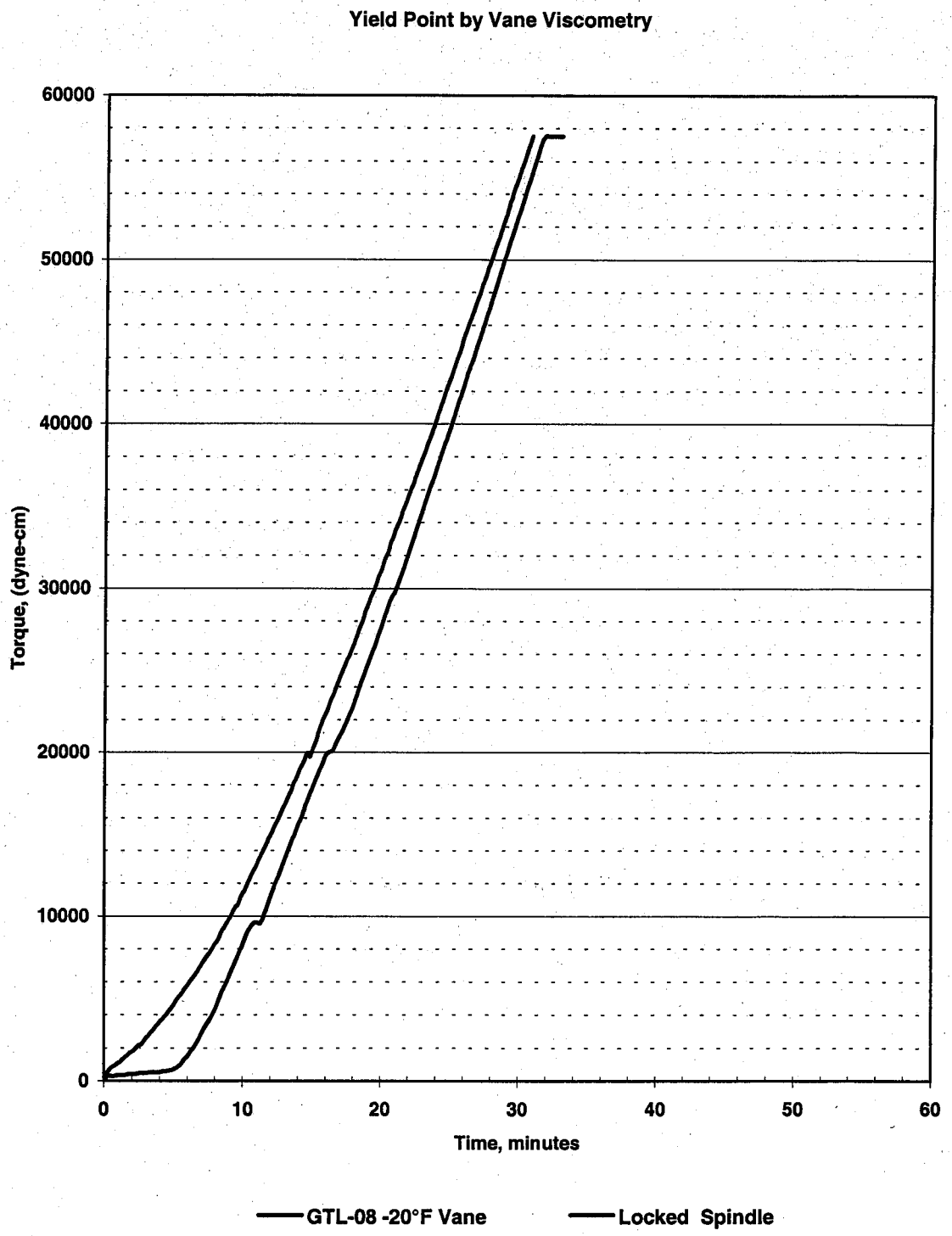


Figure 10: Sample 3:1 - 01 at 20°F RV Viscometer

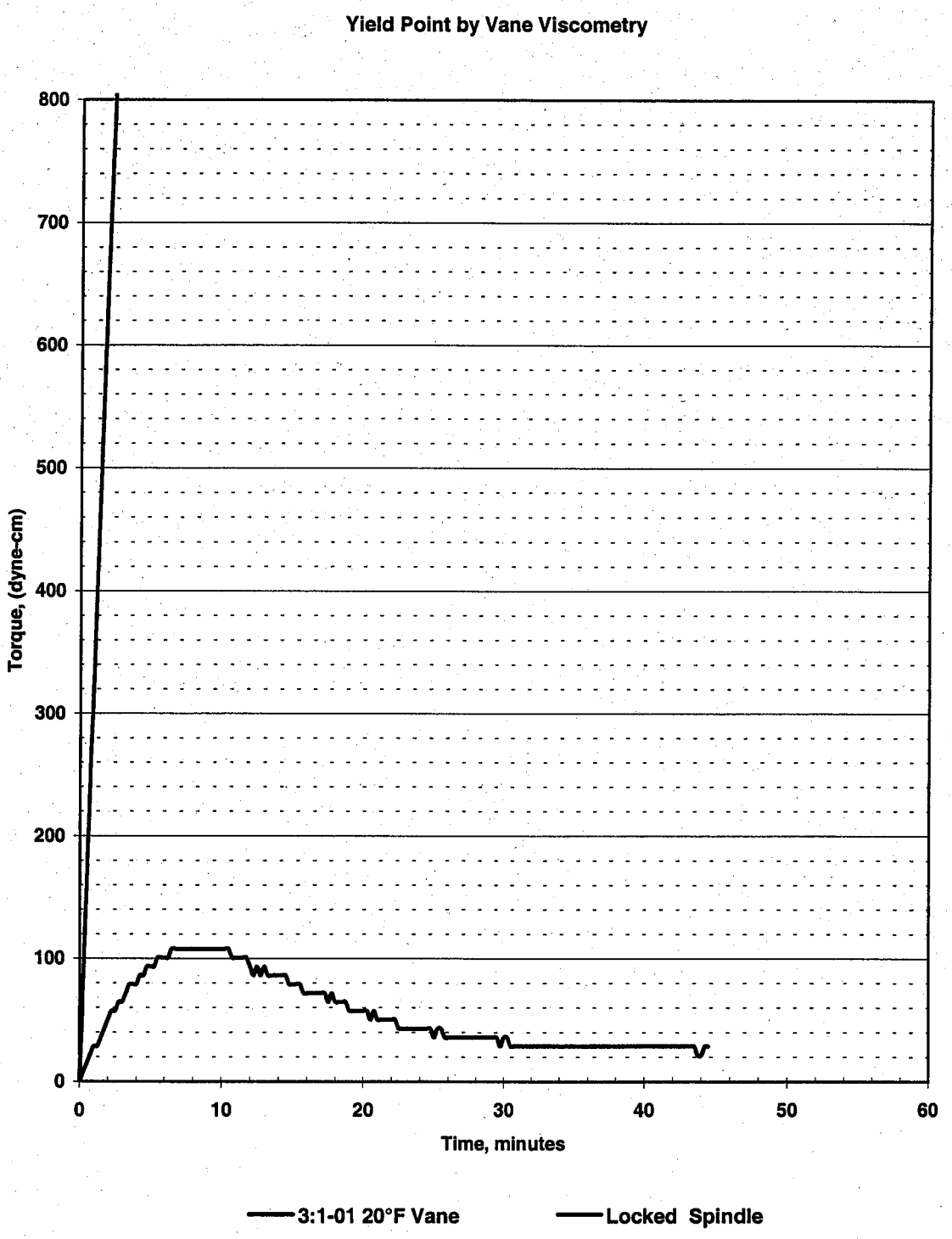


Figure 11: Sample 3:1 - 02 at 20°F RV Viscometer

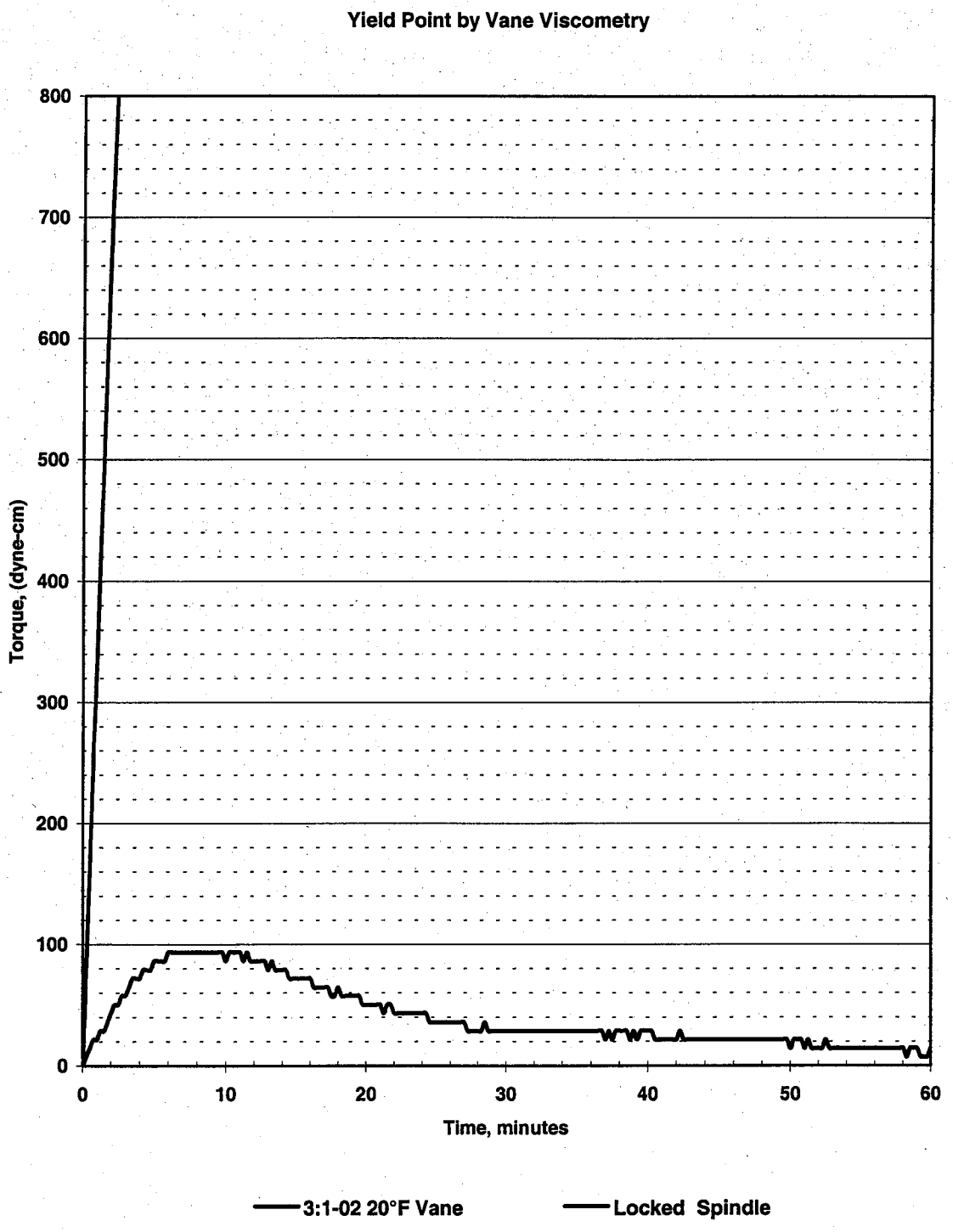


Figure 12: Sample 3:1 - 03 at 20°F RV Viscometer

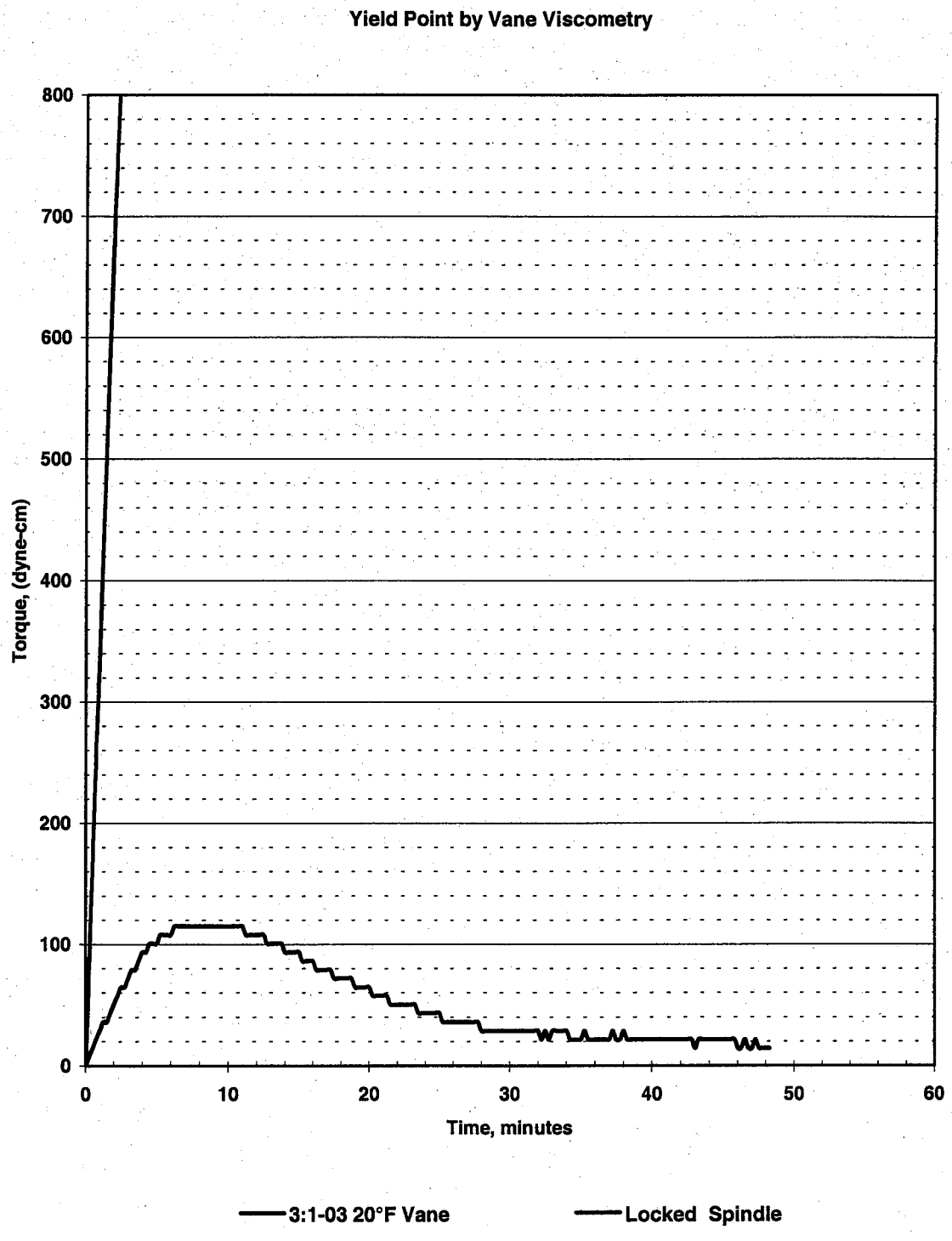


Figure 13: Sample 3:1 - 04 at 0°F LV Viscometer

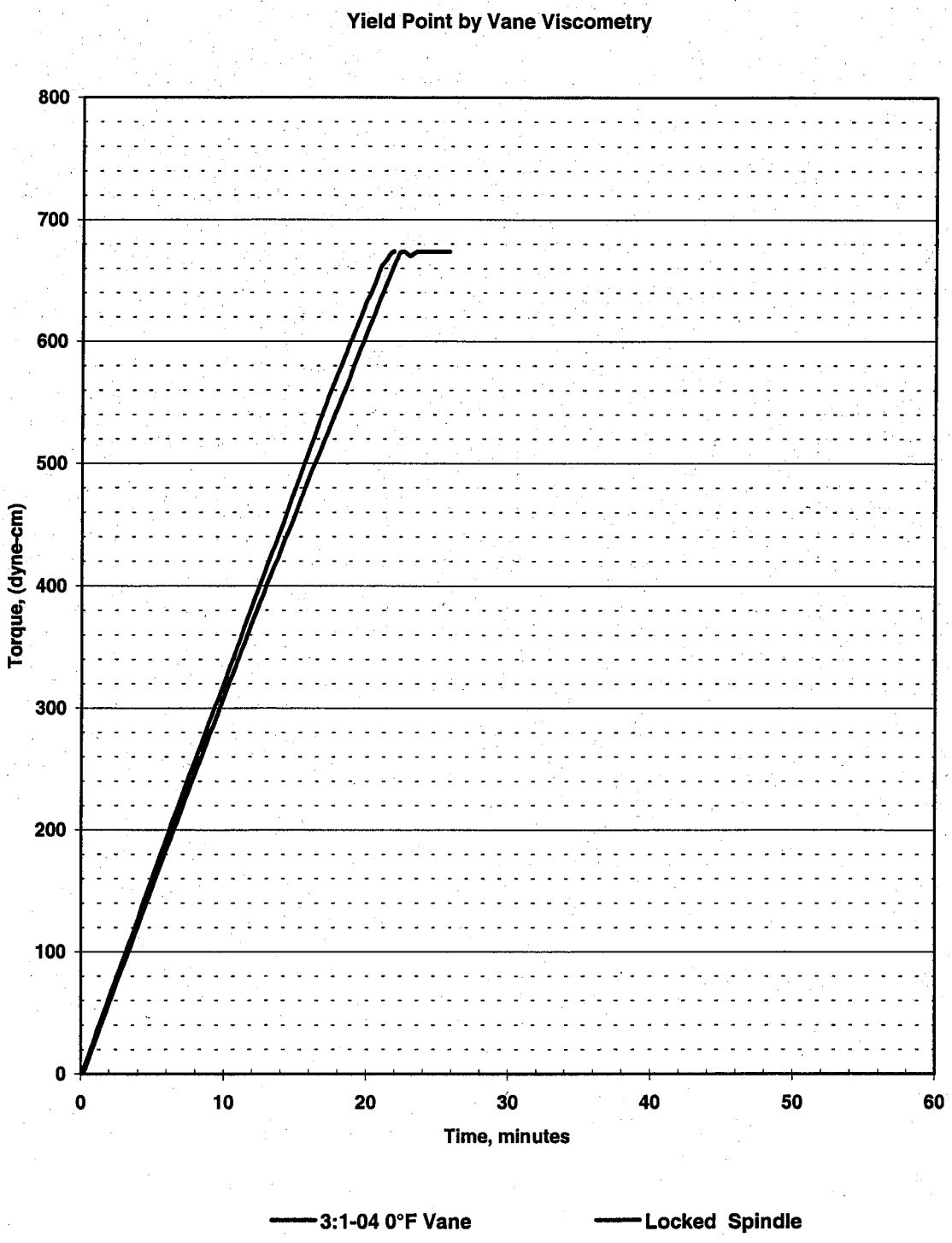


Figure 14: Sample 3:1 - 05 at 0°F HB Viscometer

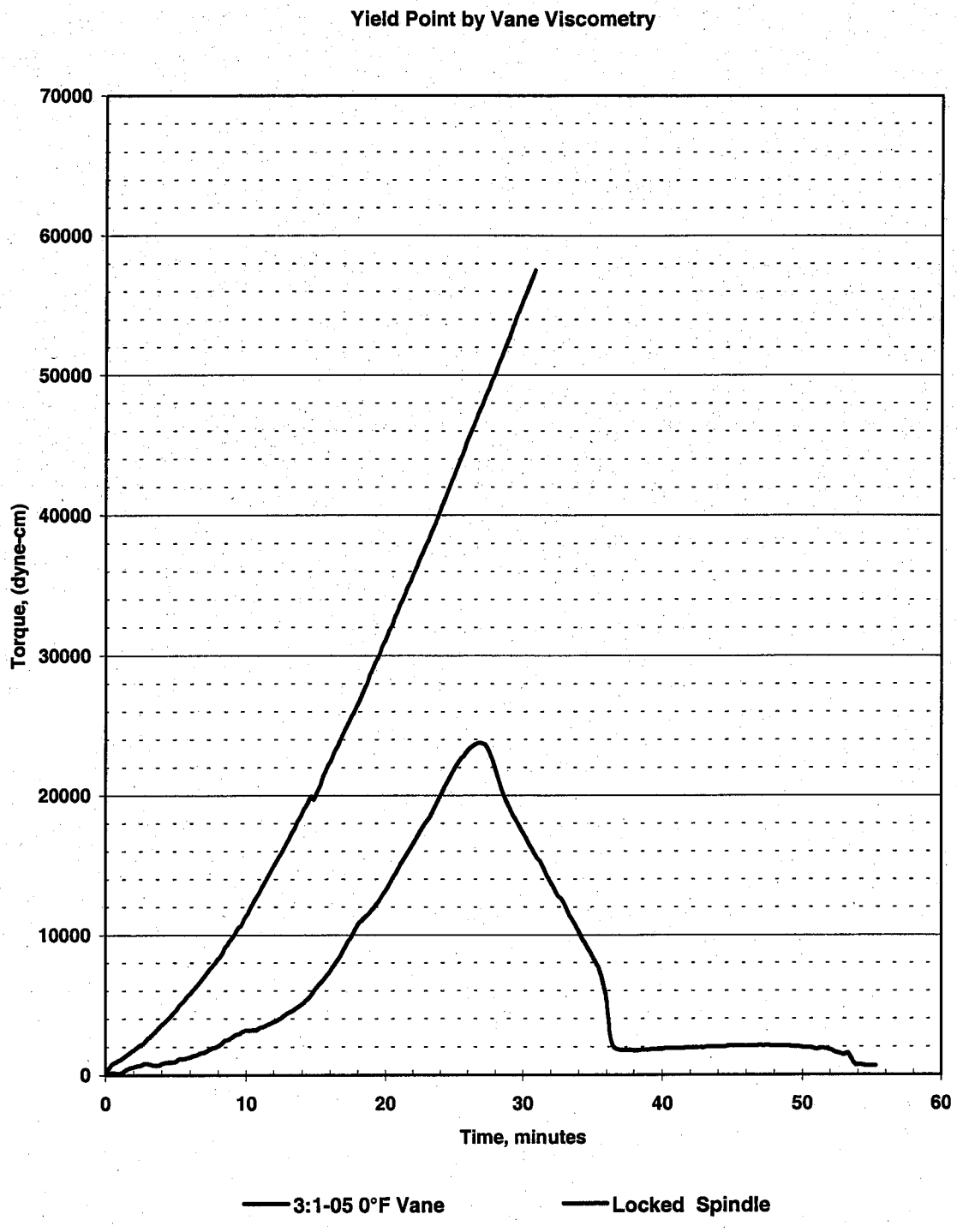


Figure 15: Sample 3:1 - 06 at 0°F HB Viscometer