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Predicting and Measuring Viscosity of Crude Oil Blends

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CCQTA
Canadian Crude Quality Technical Association

COQA

Joint CCQTA/COQA Meetings

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About Viscosity of Crude Oils

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- Crude oils are a very complex combination of hydrocarbons
- Not fully characterized compared to fuels and petroleum products
- Lack of methods for testing of crudes
- Viscosity is one of the most important properties of crude oil
- By definition, viscosity is the measurement of resistance to flow under gravity expressed in units:
  - Centipoise (mPa.sec)
  - Centistoke (mm^2/sec)
- Kinematic and dynamic viscosities are easy to convert (conversion factor is density)

Viscosity Measurement Techniques

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- Common techniques adopted in the petroleum industry:
  - Time vs. flow (glass capillary viscometer)
  - Stabinger viscosity (rotational viscometer)
  - Shear stress (cone and plate viscometer)

ASTM D445 " Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids"

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- Still reference method for viscosity in petroleum industry
- Measures "kinematic viscosity" - measurement is made while fluid is flowing under the force of gravity.
- Inexpensive hardware
- Requires longer measurement time
- Requires larger solvent volume for cleaning
- Occasionally requires recalibration of capillary tubes
- Bath temperature maintening

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ASTM D7042 "Standard Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer"

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- Measures dynamic viscosity and density and calculates kinematic viscosity
- Precise temperature control (Peltier element)
- Very popular at terminals
- Fully automated
- Wide operational temperature range
- Auto-sampler upgrade option
- Expensive
- Filling viscosity max. 1000 cP

Cone and Plate Viscometer

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- Ultimate method for heavy crude oils and bitumen
- Relatively simple to operate
- Calculates shear rate shear stress
- Temperature controlled by Peltier element (newer models)
- Some models required heating bath for maintaining temperature
- Sample size affects measurement
- Not established as ASTM standard for heavy crude oils

What Affects Viscosity Measurement

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- Maintaining test temperature has the strongest influence on the quality of a viscosity measurement
- It is best to determine viscosity at three temperatures to ensure the material is Newtonian at the test temperature.
- The viscosity measurement should be performed in the range in which crude oils are homogeneous liquids

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Significance and Use of Predicting Blend Viscosity

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- Viscosity in the upstream oil industry is primarily a transportation related measurement
- The energy to transport petroleum in pipelines is proportional to the viscosity of the fluid
- Blending technique is expensive - requires the addition of expensive light crudes to transport bitumen
- Shortage of diluent on the market
- Accurately predicting the viscosity of a blend of hydrocarbons is a common industry problem
- If done right can generate significant savings

Blending Issue - Incompatibility

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- Asphaltene can flocculate and precipitate from the blend
- Very important to monitor incompatibility in blending of Canadian oil sand bitumen, heavy synthetic crudes and diluents
- Wrong proportions of the blend components or even the wrong order in blending can cause incompatibility
- Operational problems:
  - Blend modeling do not always predict incompatibility
  - Asphaltene precipitation in storage tanks and pipelines
  - Fouling of heat exchangers and heaters

ASTM D7152-11 "Standard Practice for Calculating the Viscosity of a Blend of Petroleum Products"

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- Kinematic viscosity of a blend is estimated from kinematic viscosities of blend components and their fractions
- Not applicable to materials which exhibit strong non-Newtonian properties
- Practice describes two ways of calculations:
    - The Wright Blending Method

/more accurate - requires component viscosities at two temperatures/

- The ASTM Blending Method

/requires viscosities of components at a single temperature/

Schematic Illustration of Wright Blending Method

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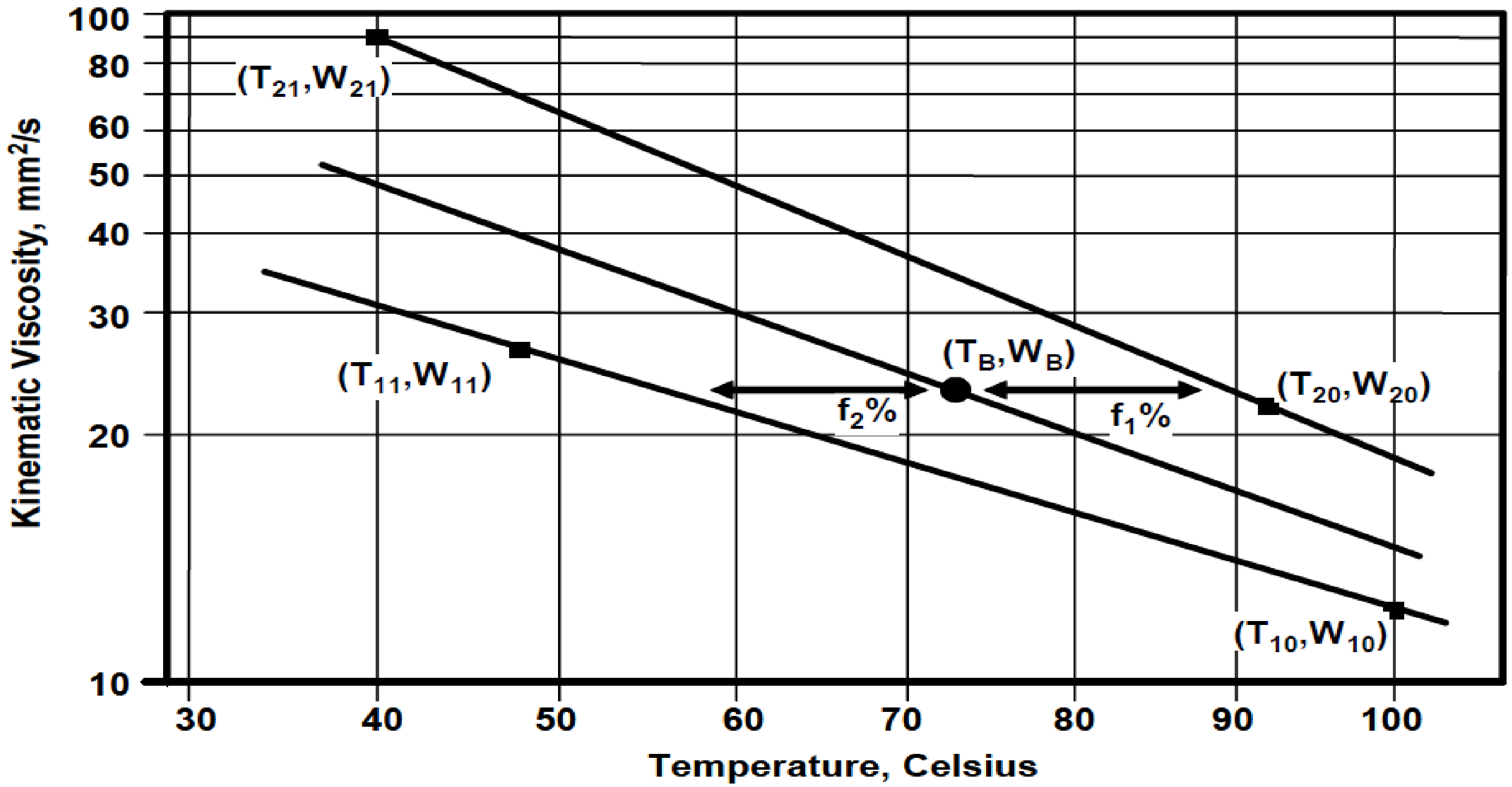

Source: ASTM D7152

Laboratory Procedure for Predicting the Viscosity of a Bitumen/Diluent Blends

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- Based on preparation of real blends and multiple measurings of blend viscosities at different temperatures
- Can indicate the problems related to incompatibility of the blend components
- Provides shrinkage value based on comparison of measured and calculated densities of the blends
- Generates very useful graphs and formulas
- Spots any problems related to non-Newtonian behavior of blends

Step 1: Blend Preparation and Density and Viscosity Measurements

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- Density determination of blend components
- Preparation of the blends by mass (for higher accuracy)

OIL TYPE:	Bitumen
DILUENT TYPE:	Condensate
SPECIFIC GRAVITY OF OIL @ 15C (kg/m3):	1001.2
SPECIFIC GRAVITY OF DILUENT @ 15C (kg/m3):	722.7

	MIXTURE A	MIXTURE B	MIXTURE C	MIXTURE D
MASS % DILUENT:	19.00	21.00	23.00	25.00
VOLUME % DILUENT:	24.5	26.9	29.3	31.6
THEORETICAL DENSITY @ 15C (kg/m3):	932.9	926.2	919.7	913.2
MEASURED DENSITY @ 15C (kg/m3):	936.0	929.4	922.8	916.0
SHRINKAGE FACTOR (THEORETICAL/MEASURED):	0.997	0.997	0.997	0.997
KINEMATIC VISCOSITY @ 5C (mm2/sec):	547	378	269	188
KINEMATIC VISCOSITY @ 10C (mm2/sec):	376	262	190	137
KINEMATIC VISCOSITY @ 15C (mm2/sec):	253	190	140	102
KINEMATIC VISCOSITY @ 20C (mm2/sec):	192	143	107	81.0

Simple shrinkage factor calculation

Step 2: Graphical Interpretation of the Measured Results

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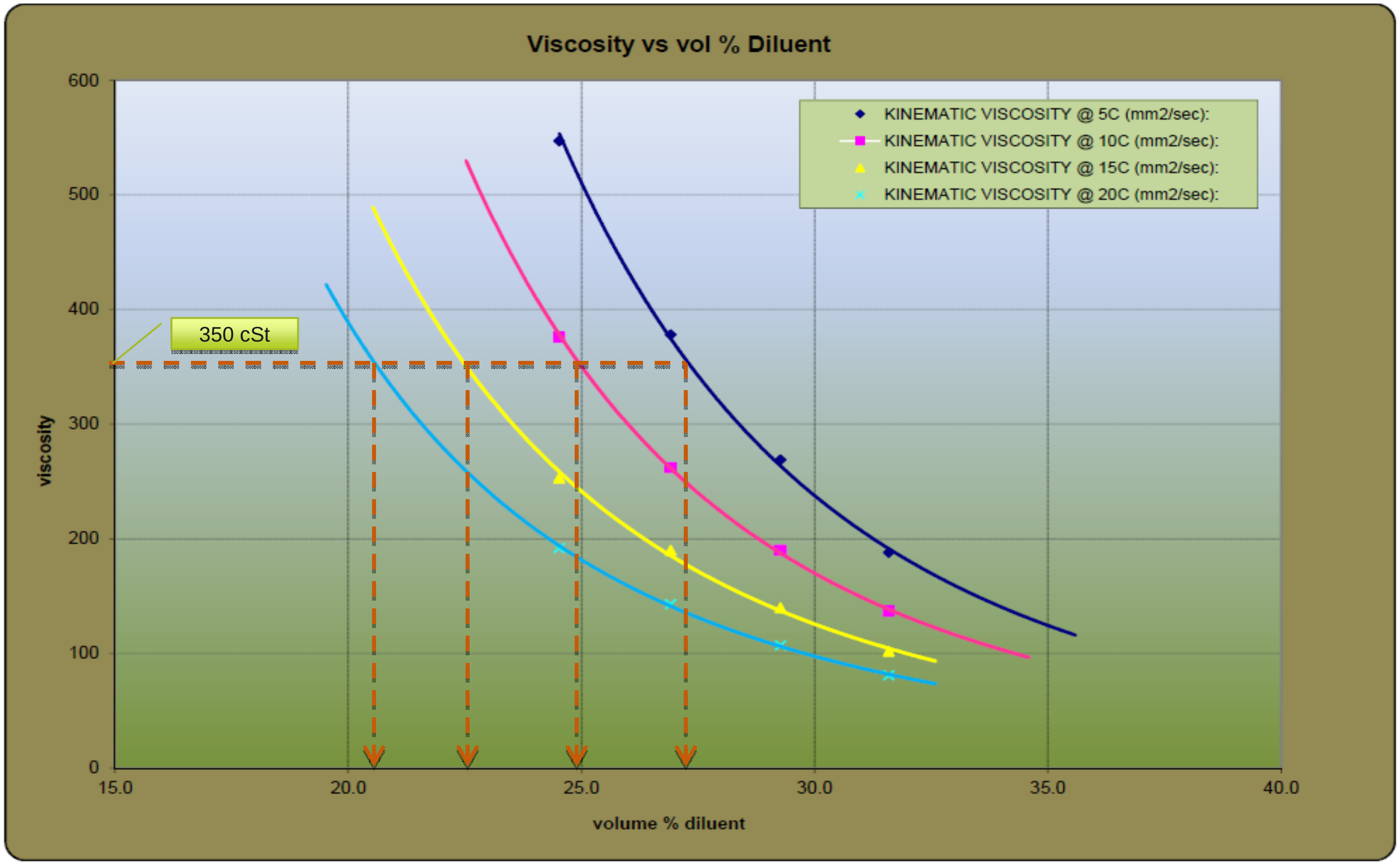
- Linear function - If viscosity is plotted in log-log graph
- Viscosity vs. mass % of diluent graph could be also generated



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Step 2: Graphical Interpretation of the Measured Results (cont.)

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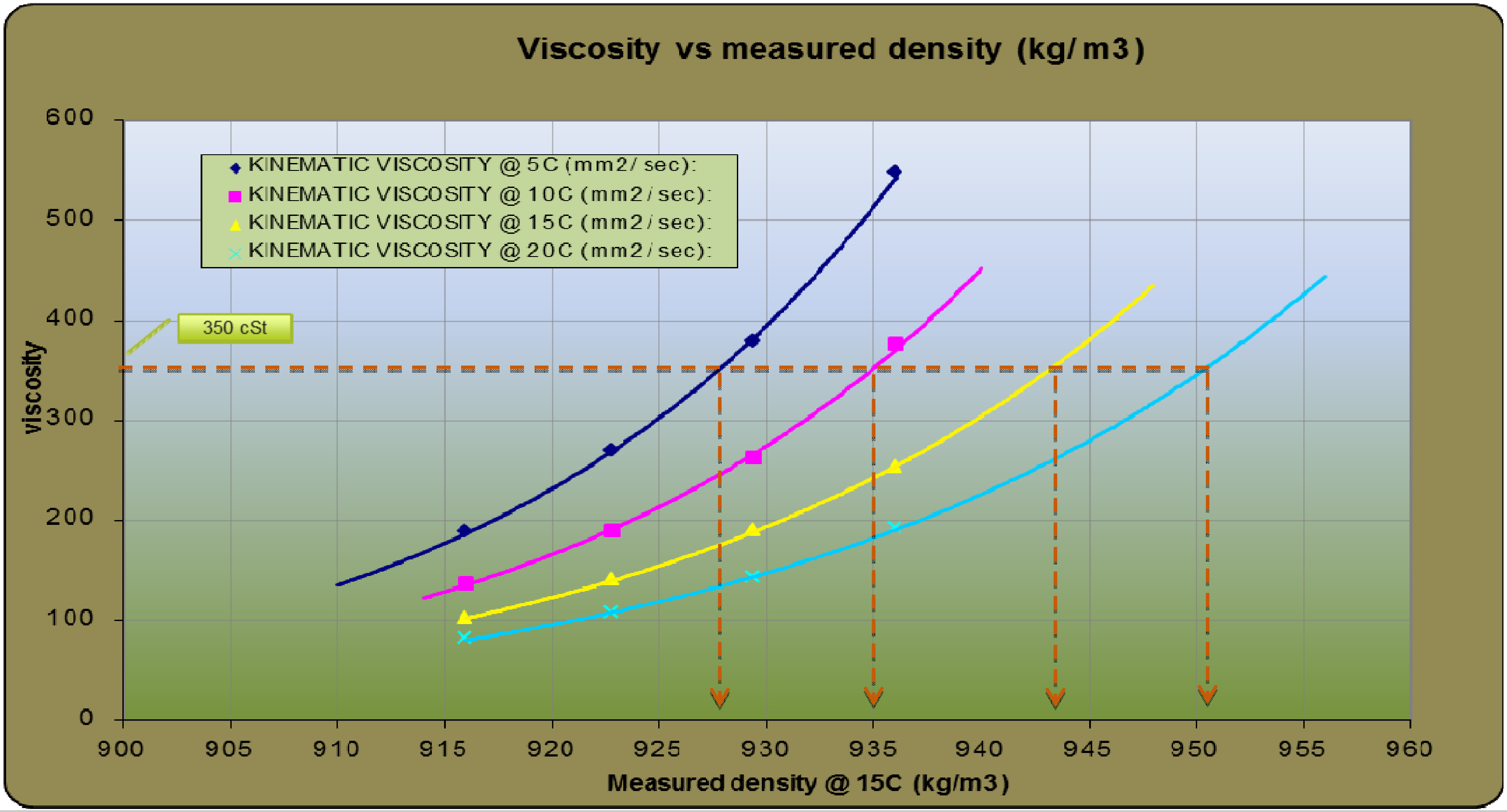

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Step 3: Prediction of Pipeline Viscosity Spec Requirement

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- Extrapolations from the previous graphs are going to generate data related to 350 cSt viscosity blend target

CALCULATED VOLUME % DILUENT REQUIRED TO ACHEIVE 350 mm2/SEC @	5.0	**degrees C:**	27.3
CALCULATED VOLUME % DILUENT REQUIRED TO ACHEIVE 350 mm2/SEC @	10.0	**degrees C:**	25.0
CALCULATED VOLUME % DILUENT REQUIRED TO ACHEIVE 350 mm2/SEC @	15.0	**degrees C:**	22.8
CALCULATED VOLUME % DILUENT REQUIRED TO ACHEIVE 350 mm2/SEC @	20.0	**degrees C:**	20.6
CALCULATED DENSITY ^{15C} (kg/m3) REQUIRED TO ACHEIVE 350 mm2/SEC @	5.0	**degrees C:**	927.8
CALCULATED DENSITY ^{15C} (kg/m3) REQUIRED TO ACHEIVE 350 mm2/SEC @	10.0	**degrees C:**	934.9
CALCULATED DENSITY ^{15C} (kg/m3) REQUIRED TO ACHEIVE 350 mm2/SEC @	15.0	**degrees C:**	943.0
CALCULATED DENSITY ^{15C} (kg/m3) REQUIRED TO ACHEIVE 350 mm2/SEC @	20.0	**degrees C:**	950.2

Step 4: Graphical Interpretation of Extrapolated Results

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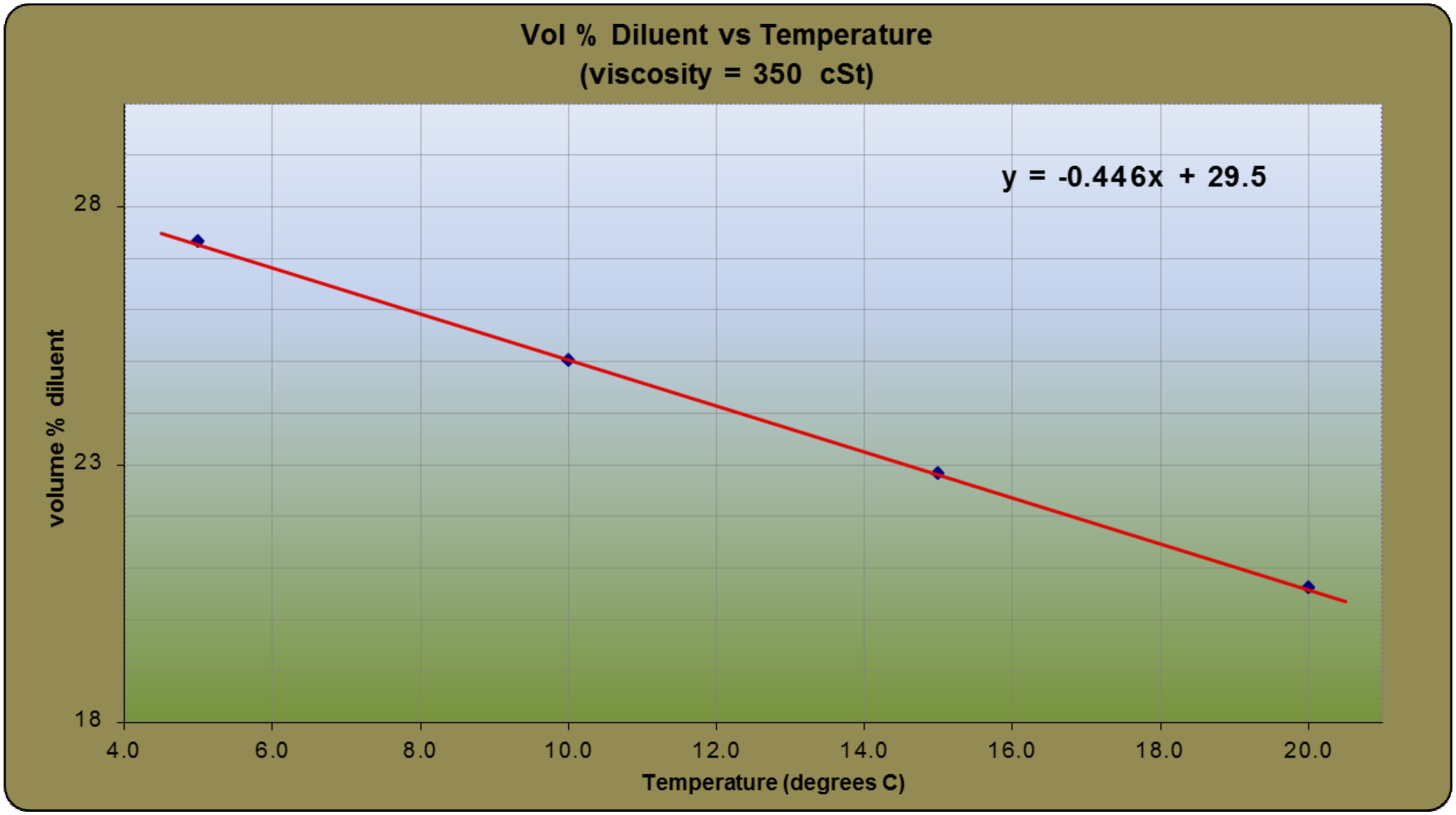

Step 4: Graphical Interpretation of Extrapolated Results (cont.)

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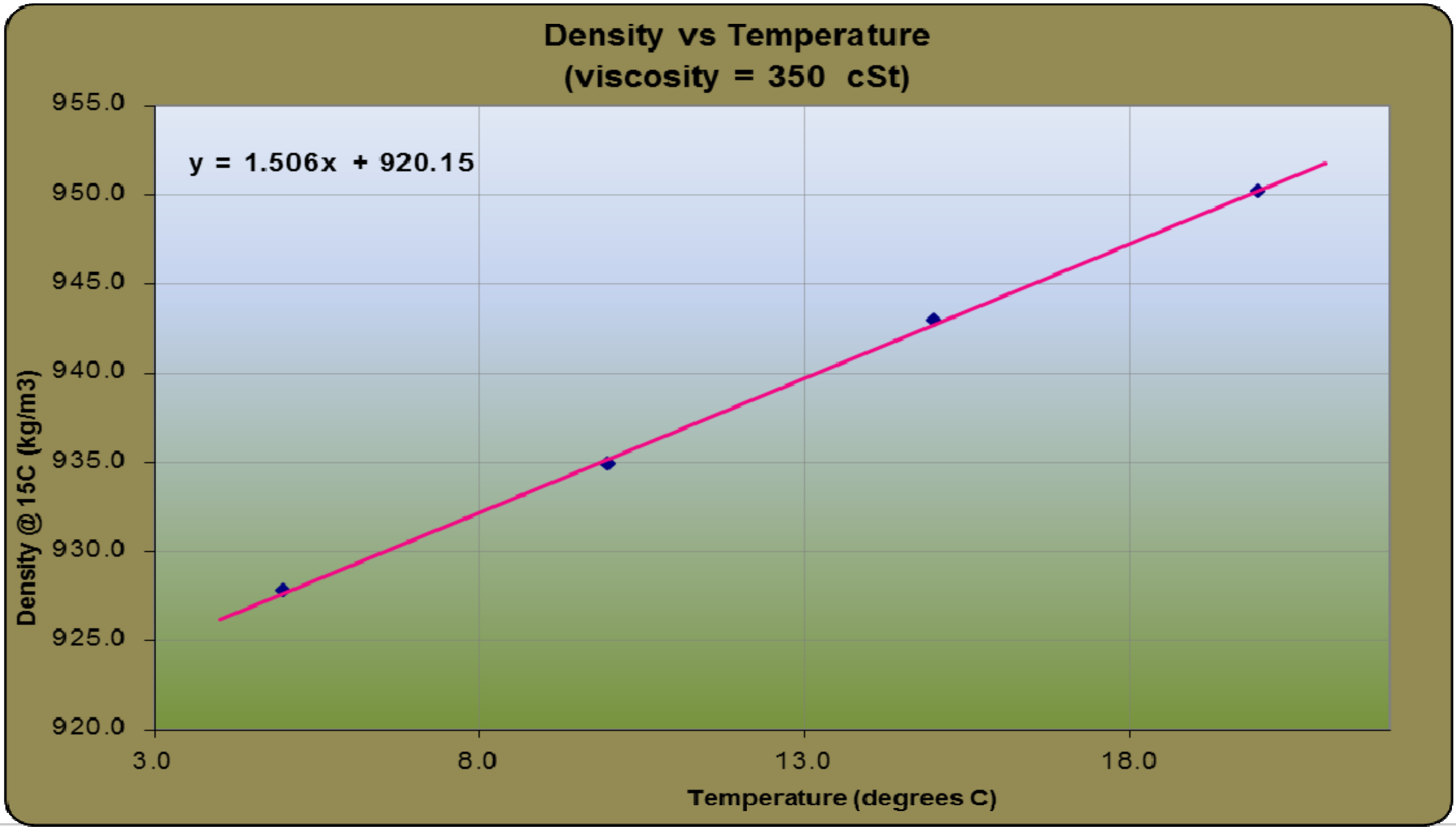

Challenges in Viscosity Measurement

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- Crude oil blends made with butane
  - difficult to precisely prepare and test the blends in lab conditions
  - difficult to keep integrity of the sample
- Viscosity of heavy oil emulsions
  - emulsion stability issues
  - non-Newtonian behavior (pseudoplastic type of fluid)
  - viscosity will decrease with an increasing shear rate
- Viscosity of heavy oil slurry (viscous hydrocarbon emulsions surrounded by a lighter viscosity liquid, such as water)
  - usually mixtures of different types of emulsions and free water
  - difficult to mimic reservoir conditions

Viscosity of Emulsions

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- Increased requests from industry to measure viscosity of emulsions
- Common rule : The viscosity of the emulsion is higher than viscosity of individual components (crude oil and water)
- Viscosities of the emulsions depend on which phase is the dispersed phase and which is the continuous phase:
    - water-in-oil emulsion
    - oil-in-water emulsion
- Lab measurement more reliable and more realistic comparing to the calculating models

Influence of Sample Preparation on Viscosity Data

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- CM Samples: prepared using ultra high-speed centrifuge
- SM Samples: prepared by solvent extraction followed by solvent removal from bitumen

Description	CM1	CM2	CM3	SM1	SM2	SM3
Absolute Density @ 25°C	1,020.0	1,019.0	1,017.0	1,015.0	1,016.0	1,016.0
Absolute Density @ 40°C	1,010.0	1,010.0	1,008.0	1,006.0	1,006.0	1,006.0
Absolute Density @ 60°C	998.1	997.5	995.4	993.5	993.4	993.6
Absolute Density @ 80°C	985.6	985.1	983.0	981.1	980.8	981.2
Sediment (mass%)	1.0	1.3	1.1	<0.1	<0.1	<0.1
Water Content (wt%)	4.6	7.8	6.6	<0.01	<0.01	<0.01

Temperatures (°C)	Dynamic Viscosity (cPs)					
	CM1	CM2	CM3	SM1	SM2	SM3
25	1,248,000	824,400	1,273,000	291,000	248,800	367,200
40	115,000	103,000	110,000	37,900	32,840	45,540
60	11,260	11,810	10,240	4,584	4,222	5,437
80	1,721	2,232	1,523	941	857	1,073

Influence of Sample Preparation on Viscosity Data (Graph)

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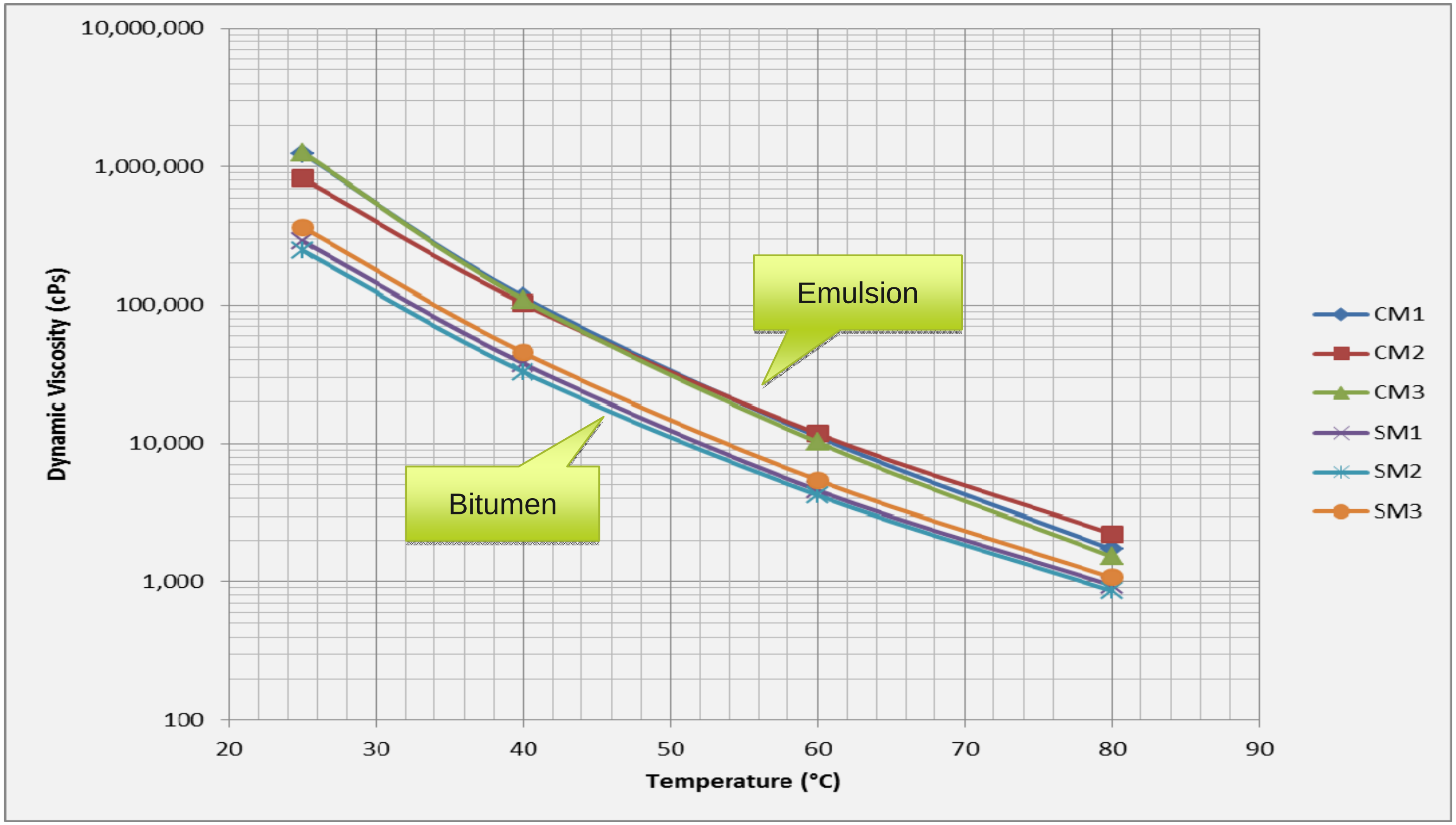

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THANK YOU

QUESTIONS ?

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