COMPUTER CONTROLLED OSCILLOSCOPE USED TO PREDICT ACTUAL THIN FILM LUBRICATION THROUGH AN END SET OF PARALLEL PLATES

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Abstract: The objective of this research is to measure, analyze and predict the effect of surface properties and study the microscopic behavior of thin lubricant. The chemical composition of the lubricant also affects the surface condition. Experimental data obtained by conducting the outlined experiments on thin film behavior is needed specially to advance the technology of sliding face seals, where leakage rate, friction and wear are important design consideration.

INTRODUCTION

After we define clearly the system being dealt with, the following effects are considered:

a)   Effect of bulk viscosity of lubricants.
b)   Effect of hydrocarbon chain length of oil.
c)   Effect of surfactant additives such as fatty acids.
d)   Effect of surfactant vs unsaturated surfactants (eg. Stearic acid vs oleic acid)

The Various fluids tested for this purpose are outlined below.

Oil	Acid	Concentration (Wt / Vol)	Solution
Light mineral Oil	Stearic Acid	0.1% 1.0%	L. Oil+ 0.1%S.A L.Oil + 1% S.A
Light Mineral Oil	Myristic Acid	0.1% 1.0%	L. Oil+ 0.1%M.A L.Oil + 1% M.A
Light mineral Oil	Palmitic Acid	0.1% 1.0%	L. Oil+ 0.1%P.A L.Oil + 1% P.A
Light mineral Oil	Decanoic Acid	0.1% 1.0%	L. Oil+ 0.1%D.A L.Oil + 1% D.A

Experimental data obtained by conducting the outlined experiments on thin film behavior is needed specially to advance the technology of sliding face seals, where leakage rate, friction and wear are important design consideration.

LABORATORY TEST EQUIPMENT

The testing contains a long screw driven piston totally enveloped in a chrome steel case. The out side diameter of the case is 7cm (2.76in) and thickness is 0.6cm (.24in). The length of the case is 58cm (22.84in). Length of screw is 19cm (7.48in). Design and fabrication is done for individual components of the rig. The frame of the rig was built from a 3/8th inch pipe. The right end of the piston contains a socket, into which a plug is inserted. We thus are able to develop an annular space through which liquid can be squeezed. There are 2 types of plugs so with which precise measurements of the predetermined settings in the film thickness can be made. The gap between the inner surface of socket & outer surface of plug forms the thin space.

There is a socket inserted between the screw drive and the piston in which an LVDT (load cell) is inserted. A circuit is devised so as to allow piston movement alternatively between two momentary micro limit switches L and R. for every run. Lubricant is poured into the piston after each run. The lubricant is drained slowly into the beaker through a nozzle as it is pumped. The motor rpm is measured using an rpm meter or phototac; light sensing device is used to detect for every revolution a taped spot on a white glazed background, mounted into the shaft pulley. One end of the rpm meter is connected to channel B of the digital siliscope so that one can obtain the signal for each run.

LOAD CELL

The term load cell designates a transducer, which has the characteristic of providing an output usually electrical, which serves as a measure of the load or force placed along the sensitive axis of the cell. The unit configuration

is usually a compact right cylinder whose and fittings extended along the longitudinal center axis of the cylinder. The central winding designated as the primary winding is excited by applying a sinusoidal voltage Vp with a typical frequency between 1000 to 5000 Hz.

The outer windings, designated as secondary windings, have equal number of turns. A ferromagnetic core moves axially within the hollow cylinder and the movements of the core varies the magnetic flux linking the primary winding to each of the secondary windings. This flux variation can be detected and forms the basis for position measurement via the LVDT. The secondary windings of the LVDT are usually connected in series so that the difference in voltage between the two windings can be detected. When the core is centered, the magnetic flux and induced voltages is both secondary windings are equal and the voltages differences is zero. As the core moves toward one secondary winding, the induced voltage in that winding increases and the induced voltage in the other secondary winding increases causing a voltage difference to appear.

The winding can be constructed so that the relationship between core position and output voltage is linear. If Vp = V sin (wt) Then the voltage difference as a function of core position x can be expressed as
    Vs = kVx sin(wt)
Where k is a constant.

A phase sensitive rectifier can be used to convert this signal into a non-sinusoidal output voltage that is proportional to core position. The magnitude of the output voltage is equal to the amplitude of the differential voltage Vs and its sign is determined by weather the differential voltage is in phase or out of phase with the signal applied to the primary winding. The output voltage after filtering is the
        Vo = KVx

The full-scale stress of every load cell is well below the endurance limit of the material, providing a long working life. Tare plus working load should not exceed 100% full scale for optimum life. To a large extent, resolution is a function of the design of the LVDT output electronics, and it tends to decrease with range. An analog-to-digital converter is required to convert the output voltage into computer-readable from performance Specification:

Linearity : Better than 0.2% full range
Resolution : Better than 0.1% full range
Repeatability : Better than 0.1% full range
Operating temperature : -65 F to + 200 F
Excitation: 1-5 V rms 400 to 10Khz
Suggested load impedance: 400 k Ohms

The various connections from the load cell to the Digital oscilloscope, function generator and external jumper through the pin outs are shown in the Figure. The colors of the wires A, B, C, D, E and F are listed below.

A	-	Red
B	-	Blue
C-	-	Green
D	-	Black
E	-	Yellow
F	-	Brown

The signal AC output of the external jumper is connected to the terminal high of the function generator. The signal 2.5Khz AC input is connected to the terminal filter in channel A. The function generator is to 2.5 KHz, the range is 0.0001 to 100 and it is set to generate a sine wave.

Calibration of Schaevitz Load Cell
Basis for the calibrating system of the Schaevitz force cells is a 300,000 lb universal testing machine, having three ranges for either tensile or compressive testing of a wide variety of force cells. The testing machine calibration is traceable to the U.S. Bureau to Standers. The Schaevitz load cell was placed on the mounting pad of the UTM. Its end was connected to one terminal of the digital oscilloscope. The next step was to add weights in steps of 10lbs. For each addition of a 10 lb weight the output rms voltage was obtained by executing program 25 (of 4094 standard pak). Each run and output rms voltage was stored in a record.

This procedure was repeated 60 times starting from 0 to calibrate the load cell to a maximum of 600 lbs. The error is ±5%. A Calibration plot for the load in lbs vs voltage rms is drawn for the 60-recorded data points. This

serves as a measure (ready reckoner) to compare the voltage rms obtained in actual operation i.e. when fluid is being pumped through a thin space between two parallel surfaces (positive displacement piston).
The uncertainty band with is estimated to be ±5%.

Specifications for 4094 Mainframe

Memory Size	16k words, 16 – bits
Addressable Subgroup:	Halves (8k), Quarters (4k)
Date Memory:	31/32 of memory size
Storage Capacity:	upto 32 waveforms
Display:	6-inch, high definition.
Expansion :	Upto x256, both axes, cursor – interactive
Numeries :	
(a) Y/T Display mode :	Time and voltage plus
(b) X/Y Display Made:	Channel No.
	Voltage and voltage plus
Displays (XY/YT)	Channel No.
a) Normal	
b) Reset numerics	Absolute Numerics
c) Grid	Relative Numerics
	Numirics Scale per grid mark
Arithmetic Functions:	
	Automatic lock of cursor to data
Autocenter	Automatic data centering
a) Unexpand Display:	Automatic check of analog zero
b) Expanded Display:	
Zero, (spring – loaded):	Analog output to X/Y or Y/T pen recorder
Pew:	
	Disk Expandable
Optional functions:	

Only the most common oscilloscope operations are covered here. This part assumes that a function generator or other signal source is available to provide input waveforms. The use of a function generator, see reference (10) or another source of input signals is required to demonstrate several 4094 oscilloscope controls important for real-life measurements.

1)   All knobs on the front panels must be in the extreme counter – clockwise positions, expect
        a)   Time per point: A
        b)   Trigger source: A

2)   All lower switches must be in the down position, expect
        a)   Channel A: On
        b)   Auto center: on
        c)   Auto/ Norm: Auto

Overview of controls

1) The function generator's output is connected to the channel A (+) input BNC and its sync output to the external trigger input BNC.
2) The channel A(+) input BNC's switch is placed to the DC position. The "DC" position allows both changing (AC) voltages and non-changing (DC) voltages to enter the oscilloscope.
3) The ± volts full scale switch is adjusted until the waveform's amplitude is as large as possible without exceeding the screen's vertical limits.
4) The time per point switch is adjusted until the waveform is easily seen.
5) The time per point switch is placed to the extreme clockwise position while observing the display. Shorter times between sample points will make the waveform to appear stretched out.
6) The time per point switch is moved one step at a time in the counter – clockwise direction.
7) The horizontal expansion switch is turned until the waveform can be easily seen. There are obviously more than enough points to define the waveform.

8) The time per point switch, is moved one step at a time, in the counter – clockwise direction. Long enough time between switch settings is given to see the display actually change to reflect a new data point spacing.
9) The horizontal expansion switch is placed to the off position in order to view the pattern of data points due to visual aliasing.
10) The time per point switch is turned even further in the counter – clockwise direction.
Note: The best time per points is always selected by beginning the search at the fastest time per point setting and slowly work toward the slower settings. In this manner and it is easy to avoid accidentally stopping on a time per point, which is too slow for the input.

Storage control buttons (viz: Hold last, live and hold next) are not complicated and are essential for even the simplest 4094 oscilloscope operation. Hold last – it holds the acquired data points in the internal memory of the 4094. Hold last should be pressed if the current display is to be saved.

Live – it does not permanently hold any data points in memory. Allows continuous points in memory. Allows continuous sweeps across the screen displaying the input signals. Live is a very powerful front panel control. Hold Next – It holds the data points acquired on the next sweep in the 4094 internal memory. The most common situation is to press Live and then Hold Next before a new sweep is sweep in the display memory. Once the data is saved, only the Hold Last LED will be illuminated.

11) The live button is pressed.
12) While in the middle of the sweep, the Hold last button is pressed.
13) The live button is alternatively pressed.
14) While in the middle of the sweep, the hold Next button is pressed.
15) Once the live button is pressed. Sweep resumes across the screen.
16) The trigger view switch is placed to the view position.
17) The trigger source switch is still set at " A"
18) The live button is then pressed.
19) The trigger source switch is rotated to the EXT position and then back to "A"
20) The trigger level control is adjusted until the two horizontal lines intersect with the waveform.
21) The trigger slope switch is placed to the " DEAL" then "+" positions while observing the display.
22) Switch from Auto triggering to Norm triggering and then back again to Auto.
23) Turn the trigger view off (Switch down position).

Function Generator

Description
The Function – Generator is a compact Voltage controlled generator with 10 decades of range. DC offset and external voltage control provide wide versatility. A fast rise time sync output is provided. Aspect ratio of non-symmetrical function is 15% / 85%.

The function generator is a multi- waveform signal source capable of very wide frequency coverage. Available are functions ranging from modulation, sweep and trigger / gated waveforms. These units provided the full range of commonplace waveforms such as sine waves, Square waves, triangle and ramp waves. The function generator is an indispensable general purpose signal source for production testing, instruments repair and the electronics laboratory.

Specifications
Output waveforms: Sinusoidal, square, triangle, positive pulse, negative pulse, positive ramp and negative ramp, pulses and ramps have a fixed 15% or 85% duty cycle.

Frequency: 0.0005 Hz to 5 MHz: ± 4%
Reference: 1 KHz at full amplitude into 50 ohms.

Signal Cycle
External trigger (as coupled) requires a positive going square wave or pulse from 1V p-p to 10V p-p. The triggering signal can be dc offset, but (Vic peak + Vic) $\leq \pm 10V$ ext gate (dc coupled) will trigger a single cycle on any positive wave from $\geq 1V$ but $\leq 10V$ which has a period greater than be period of the 3310 output. The gate signal cannot exceed 10V.

Multiple Cycles

Manual trigger will cause the 3310B to free run when depressed. When the trigger button is released, the waveform will stop on the same phase as it started. Ext. gate will cause the 3310B to free run when the gate is held at between +1 and +10V. When the gate signal goes to zero, the 3310B will stop on the same phase as it started.

Experimental Procedure

The step by step experimental procedure for each run corresponds to
a) Particular flow rate
b) Particular fluid
c) Particular concentration
d) Particular rpm

A unique feature of the test rig is its ability to read the displacement of load cell as a pressure difference using an Analog to Digital converter for each type of flow rate required. The signal as well as the AC rms Voltage can be recorded for each run by executing program rms using a digital siliscope as fluid/lubricant is being pumped.

Pitch of screw = 1/20 = 0.05" (Viz. distance traveled for one revolution).

This will be used in the calculation of the experimental flow rate. Fluid / Lubricant is essentially pumped by coupling the piston shaft to a variable speed motor through a screw drive. Periodically for every 10 runs, the chord from the function generator high is connected to the positive terminal of the Oscilloscope channel A filter and the adjusted to 10.0mV.

Program RMS

RMS moves the selected wave – form to the center of the screen, computers the root mean square (RMS) between the selected start and ending points and stores this value in the last data point of the wave – form (far right side of screen) and then displays the average voltage with the horizontal cursor at the correct level. No other data points are changed.

Note: Positive and Negative wave – form voltages are taken with respect to the original acquisition zero voltage level.

The program prompts the user student to select a starting and end point on the chosen waveform using the vertical cursor. For convenience during multiple operations, selected starting and ending points remain in the memory and are automatically recalled if RMS is used repeatedly.

When RMS is first recalled, the starting and ending points are automatically selected as the first and last points on the displayed wave – form.

If multiple wave – forms are displayed; only the wave – form on which the vertical cursor is resting will be processed (use auto center to make the selection clear). The plug-in / channel form (e.g., 1A=plug –in #1/Channel A).

The calculated RMS voltage is dependant on all characteristics of the waveform including the DC offset, symmetry, duty cycle, and number of cycles chosen, (integral number or non-integral number).

Requirements
a) Mainframe must be in YT
b) This program repositions the displayed wave-form(s) to screen center.
c) One waveform may be processed at a time.
    V1 = Selected first point
    V2 = Selected last point.

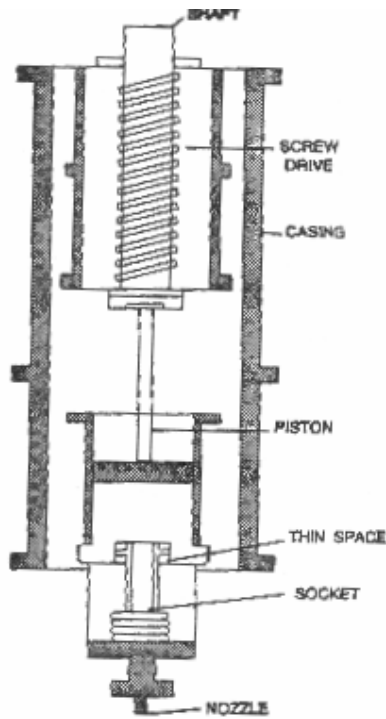$$\text{Computed } V_{RMS} \quad \sqrt{\frac{\sum_{n=1}^{K} (V_n)^2}{k}}$$

Figure 1: Cross-sectional view of a positive displacement position with end connected set of thin spaced parallel plates.
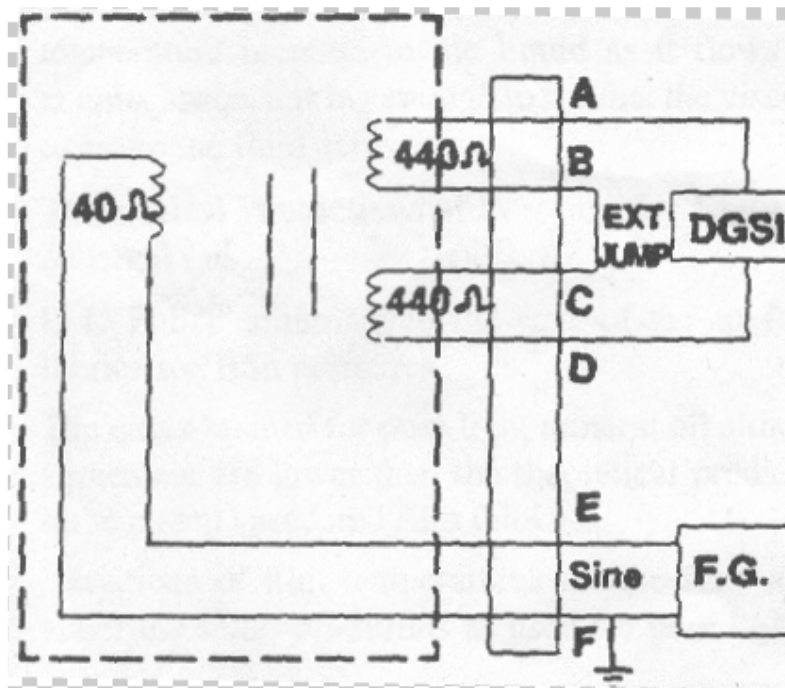

Figure 2: External circuit connecting load cell to electronic instrumentations
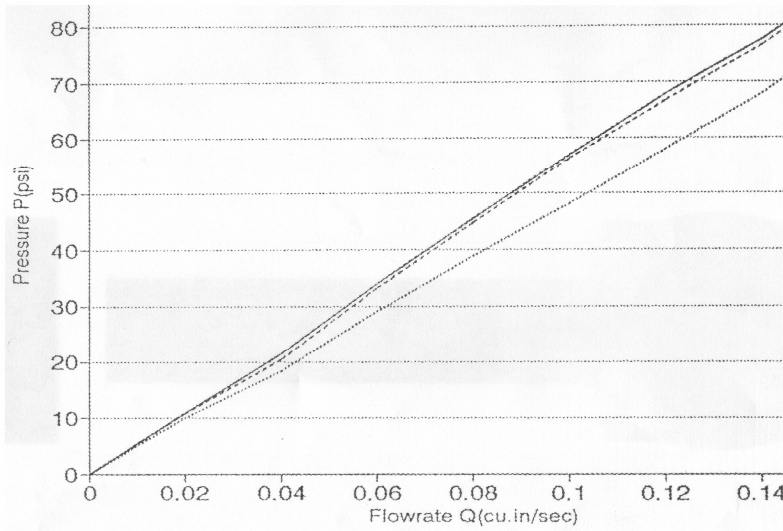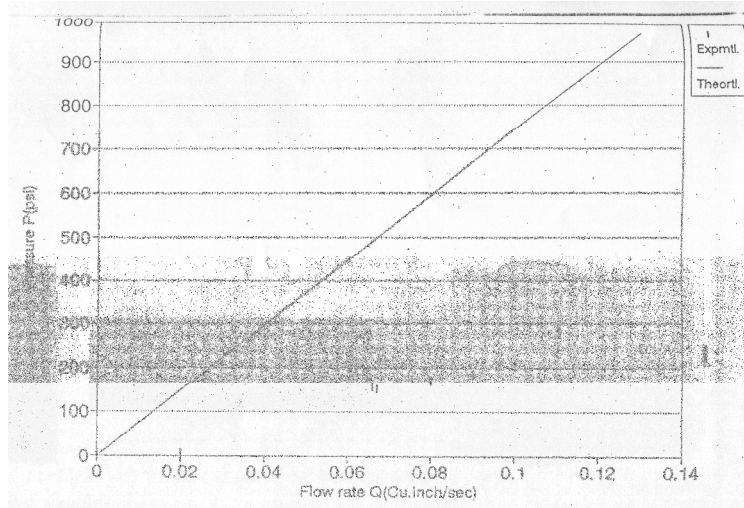
Figure-3: light mineral oil + 1%Palmitic acid

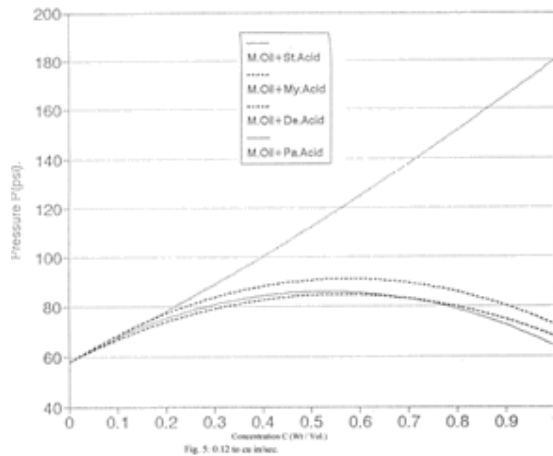**Figure 4:** 0,0.1,1% Decaonoic acid + light mineral oil

Figure-5: All acids 0.12cu/in flow rate

MATHEMATICAL FORMULATIONS
Theoretical Predictions
Flow rate at any point within a boundary film will depend on pressure gradient, and local film thickness will depend on pressure gradient, local viscosity and a permeability factor as defined below.

$$P = \left(\frac{12u\ X\ 1}{Bh3} \right) Q$$

Where

Q= flow rate;   b = Width of face
P= change in pressure; h = film thickness
μ= Viscosity   L = length of socket

Local flow rate is driven by local pressure gradient and the magnitude of the flow depends on fluid viscosity and a permeability factor.

Experimental Predictions
From the data obtained by measurement we take into consideration the rpm for each particular run for each particular type of fluid.

We calculate the flow rate using the equation
Q = rpm X pitch of the screw X area.
We are able to determine the pitch of the screw by the formula
1/20" = 0.05"
The large differences between experimental and theoretical pressures are attributed to the major viscous or friction forces

RESULTS AND DISCUSSION
The experimental data obtained for pure light mineral oil and the light mineral oil- fatty acid solution are compared to that data obtained using a theoretical analysis approach given by fuller. An additional package illustrating the combined results for the various fatty acid solutions using a statistical regression analysis is also presented.

Experimental Measurements with various Fatty Acid Mixtures in Light Oil
The solutions comprising .1% or 1% (wt/ vol) ratio of either C10, C14, C16, C18 acids with mineral oil were made and tested. The film thickness using both the plugs was varied in much the same way as for the pure light mineral oil tests.

It is seen that as concentration is increased the viscosity increases and hence operating experimental pressures increase in each case. Variations of film temperatures for the fatty acid mixtures under the same conditions as used for pure light mineral oil reveals that fluid friction is greater when fatty acid is added to pure light mineral oil, The limiting coefficient for the mixture correspondence to the coefficient of acid acting alone. Figure 3 show theoretical and experimental pressure profiles for light mineral oil + 1% Palmitic Acid under test.

Comparison of Advanced Theoretical and Experimental Results:
This section explains the results of a particular acid or acids, the theoretical pressure profiles of which are grouped together for the concentrations 0,0.1% and 1%. Figure 4.shows the group theoretical pressure profiles for all concentrations pertaining to light mineral oil and Decanoic acid. The peak pressure as well as the slope of the pressure profile increase with concentration.
This can be explained by simple equation
$P2 – p1 = loss = flv2 / (2gd)$
Where $f = 16/Re = 16\mu/(4Rh\xi)$

Therefore with increase in concentration viz. viscosity the friction force is more and since velocity being constant greater pressure is required to pump the fluid.

The second stage of advanced experimental results show the profile of pressure vs concentration for the flow rates tested. The inorganic salts present increase the specific gravity of the aqueous phase, affording more convenient centrifugation of the lower aqueous layer also exerting a desirable effect on limitation of over emulsification of the solid stearic acid. Figure 5.show the concentration vs pressure profiles for all the different types of fluids for the 0.12 cu. in/sec flow rate.

SOFTWARE

This section includes the programming and statistical methods employed for determining the pressure profiles. The code used pertains to program RMS or program 25 of a standard package. The same program is used for determining the pressures of all the different types of fluids used in the testing.

"FORTH" an application software/ language is used for the algorithmic iterations. Forth is a language for doing functional programming with a specific orientation to wards productivity, reliability and efficiency. It represents a modern way of approaching programming input data for the listing pertains to the existing conditions for each test run.

CONCLUSIONS

The addition of fatty acids in the range C10 – C18 produced an increase in hydrodynamic pressure above that developed by the pure light mineral oil lubricant. The fatty acid increased the effective viscosity of the carrier fluid causing not only an increase in pressure but also an increase in fluid temperature.

A shift in the position of the peak pressure was observed and this shift is towards minimum film thickness. Also there appears to be a sloping upward of the pressure profile with increase in flow rate. From the study of preliminary experimental and theoretical results it can be concluded that:

1) The fixed geometry setup is useful for the comparison of different fluids.

2) The assumption of p=0 does not appear to be adequate for developing the pressure profile as the experimental pressure does not correlate with those obtained theoretically.

The pressure profiles of the same acid in different concentrations show good results for all the acid when grouped together with the slope of 1% acid being the most, next 0.1% and last 0%.

The conclusions for the concentrations vs pressure profile are based on the following:
a)   In the presence of inorganic salts, there is a decrease of surface and interfacial tensions.
b)   The effect of surface tension lowering is correctly ascribed to ions of appropriate charge, which lower the critical concentration of micelle formation.
c)   In an oil solution like in aqueous, the aggregation number appears to increase in hydrophobic group, and with increase in the binding of the counternious to the micelle in icons.

In an oil medium the critical Micelle Concentrations, CMC, decreases as the number of carbon atoms in the hydrophobic group increases to about 16.

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