



PERFORMANCE AND USE OF BRINES
AS COMPLETION AND WORKOVER FLUIDS IN
OILFIELD APPLICATIONS

SEMINAR



SYNERGY FLUIDS

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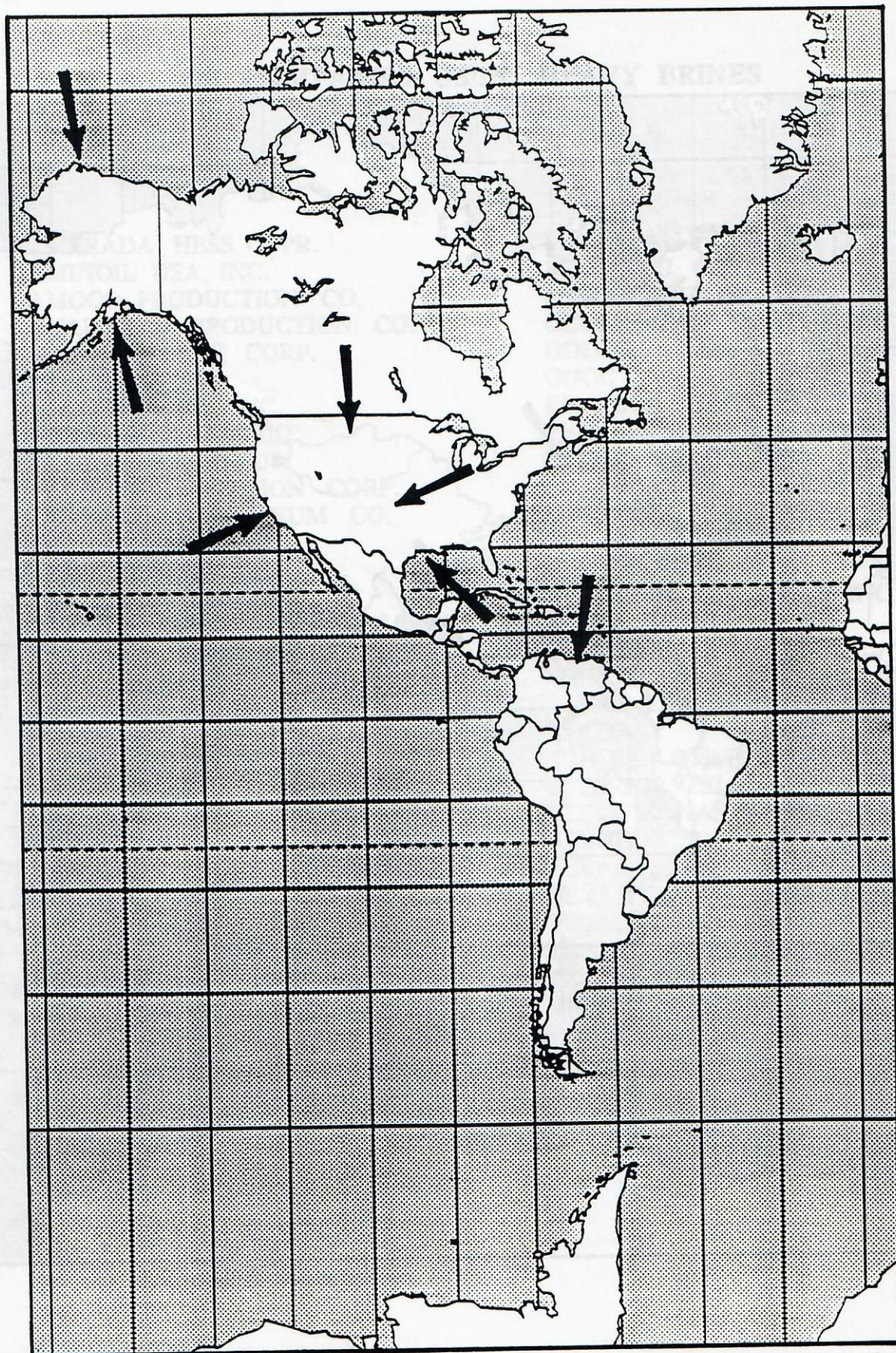
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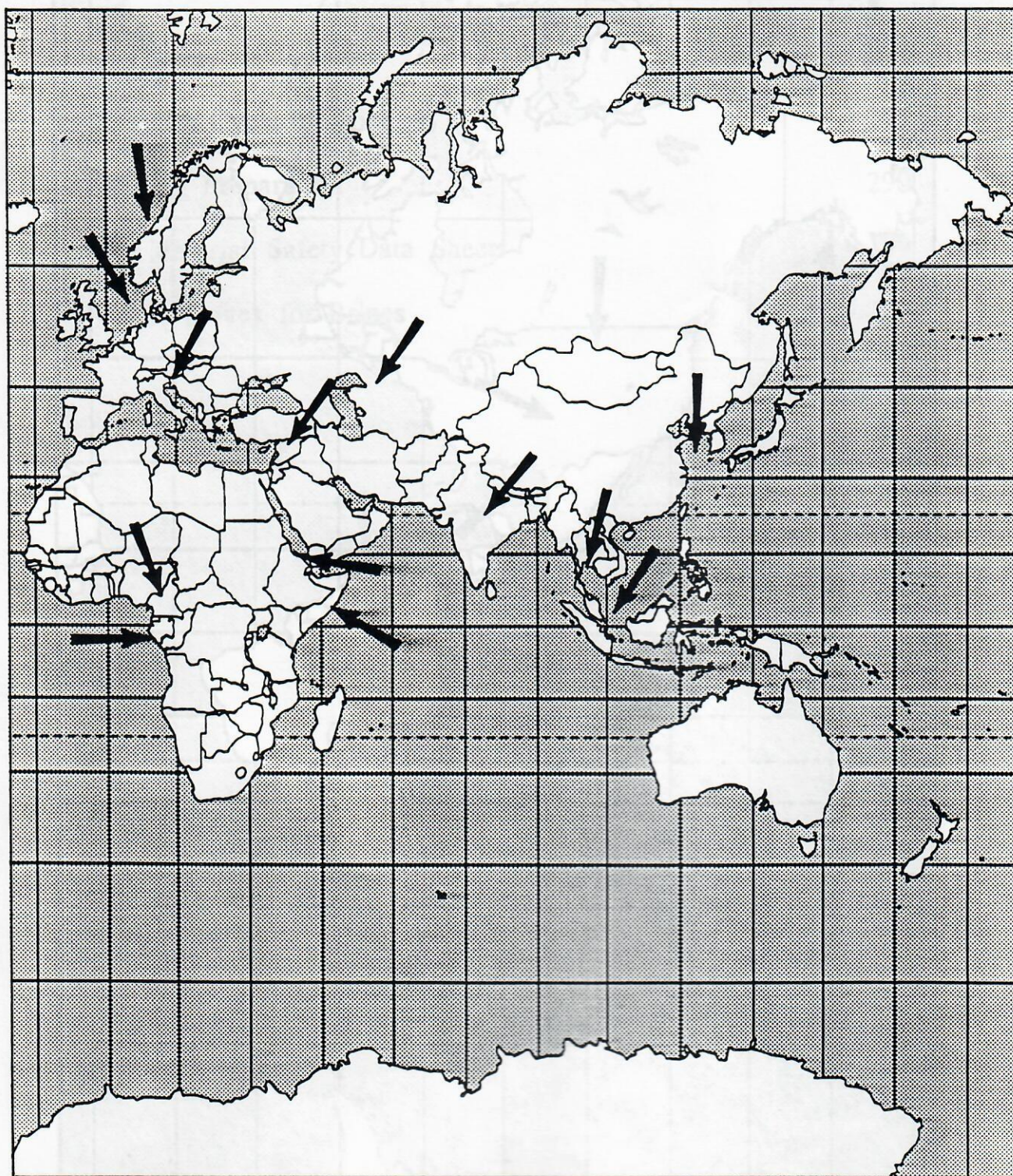
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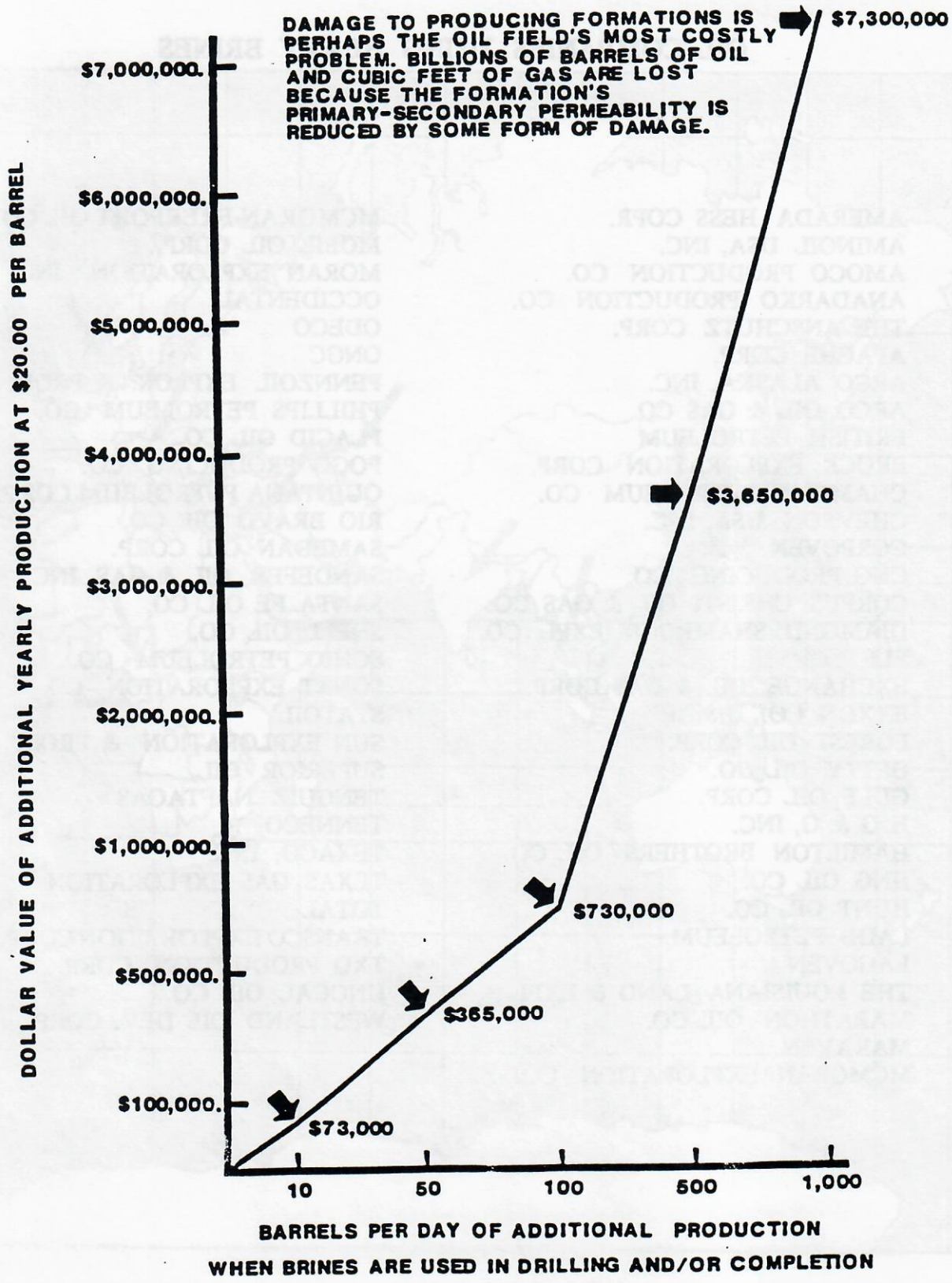
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OIL COMPANIES USING HEAVY BRINES

AMERADA HESS COPR.	MCMORAN-FREEPORT OIL CO.
AMINOIL USA, INC.	MOBIL OIL CORP.
AMOCO PRODUCTION CO.	MORAN EXPLORATION, INC.
ANADARKO PRODUCTION CO.	OCCIDENTAL
THE ANSCHUTZ CORP.	ODECO
APACHE CORP.	ONGC
ARCO ALASKA, INC.	PENNZOIL EXPLOR. & PROD.
ARCO OIL & GAS CO.	PHILLIPS PETROLEUM CO.
BRITISH PETROLEUM	PLACID OIL CO.
BROCK EXPLORATION CORP.	POGO PRODUCING CO.
CHAMPLIN PETROLEUM CO.	QUINTANA PETROLEUM CORP.
CHEVRON USA, INC.	RIO BRAVO OIL CO.
CORPOVEN	SAMEDAN OIL CORP.
CNG PRODUCING CO.	SANDEFER OIL & GAS, INC.
CORPUS CHRISTI OIL & GAS CO.	SANTA FE OIL CO.
DIAMOND SHAMROCK EXPL. CO.	SHELL OIL CO.
ELF	SOHIO PETROLEUM CO.
EXCHANGE OIL & GAS CORP.	SONAT EXPLORATION CO.
EXXON CO., U.S.A.	STATOIL
FOREST OIL CORP.	SUN EXPLORATION & PROD.
GETTY OIL CO.	SUPERIOR OIL
GULF OIL CORP.	TENGUIZ NAFTAGAS
H G & G, INC.	TENNECO
HAMILTON BROTHERS OIL CO.	TEXACO, INC.
HNG OIL CO.	TEXAS GAS EXPLORATION
HUNT OIL CO.	TOTAL
LADD PETROLEUM	TRANSCO EXPLORATION CORP.
LAGOVEN	TXO PRODUCTION CORP.
THE LOUISIANA LAND & EXPL.	UNOCAL OIL CO.
MARATHON OIL CO.	WESTLAND OIL DEV. CORP.
MARAVEN	
MCMORAN EXPLORATION CO.	



PREVENT FORMATION DAMAGE

LOWEST OVERBALANCE

AVOID PRESSURE SURGES

PROPER HYDRAULICS - AVOID LOST CIRCULATION

PROPER MUD PROPERTIES

SOLIDS CONTROL

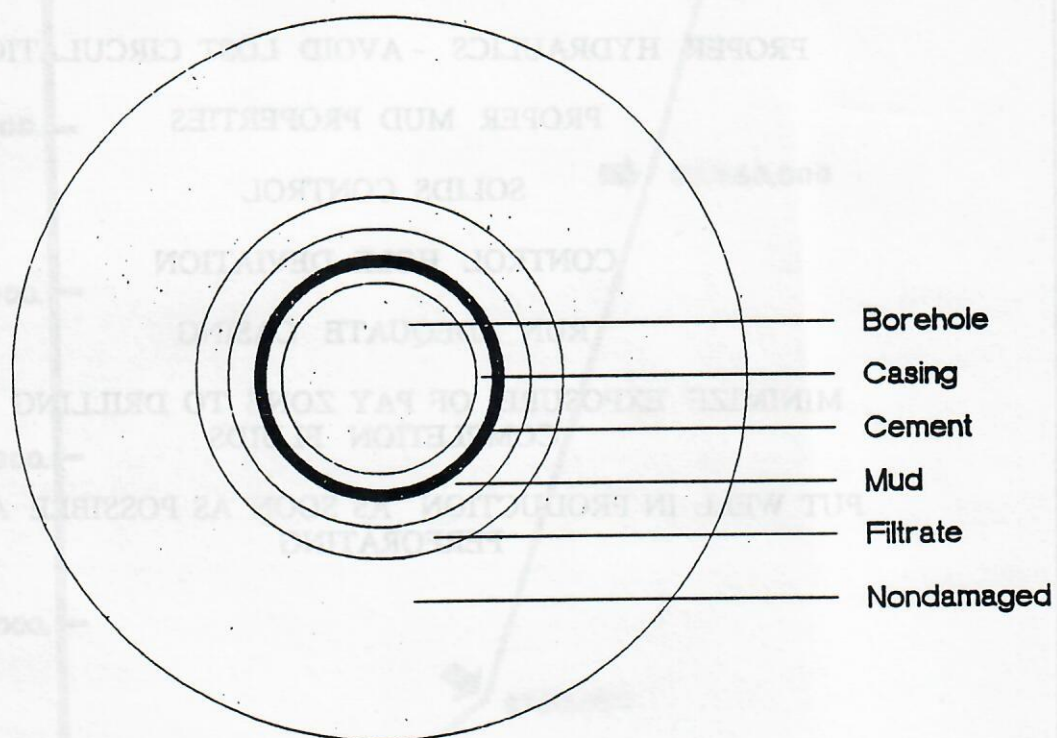
CONTROL HOLE DEVIATION

RUN ADEQUATE CASING

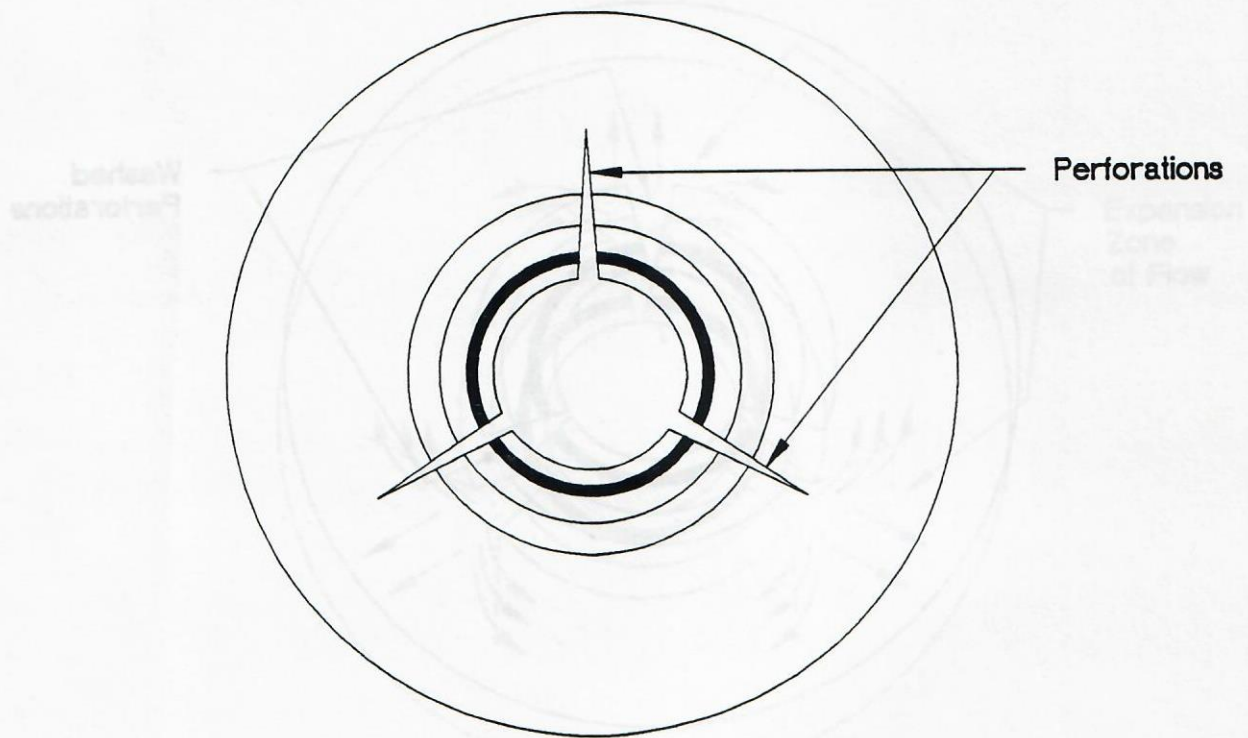
**MINIMIZE EXPOSURE OF PAY ZONE TO DRILLING AND
COMPLETION FLUIDS**

**PUT WELL IN PRODUCTION AS SOON AS POSSIBLE AFTER
PERFORATING**

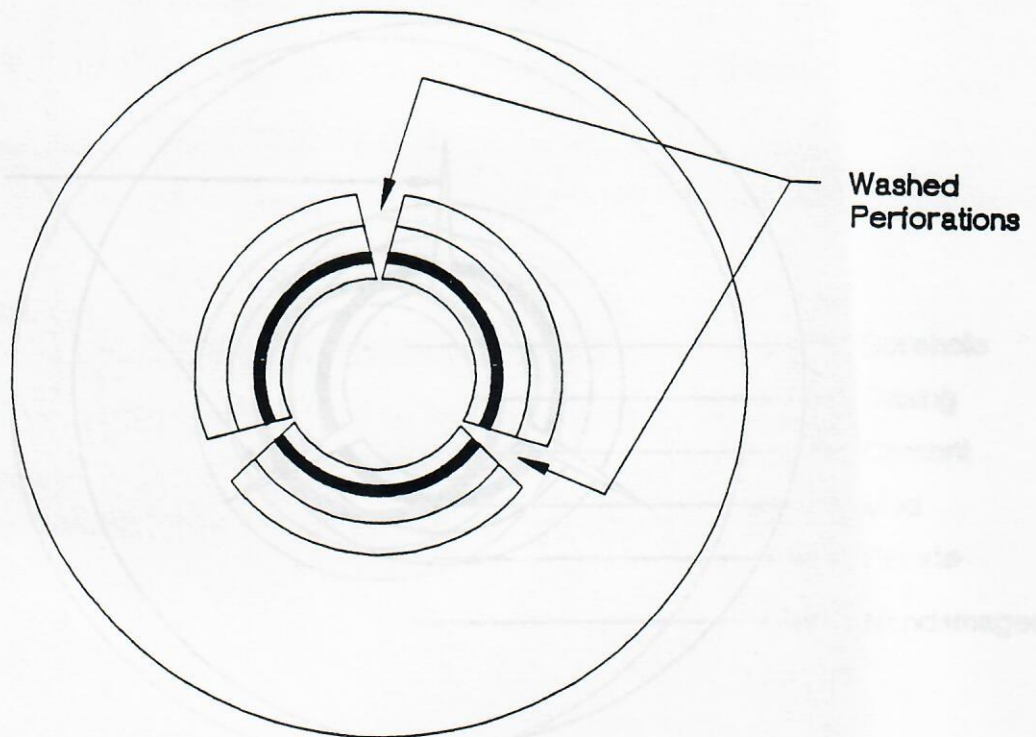
CONFIGURATION SURROUNDING WELLBORE



PERFORATIONS INTO PAY ZONE

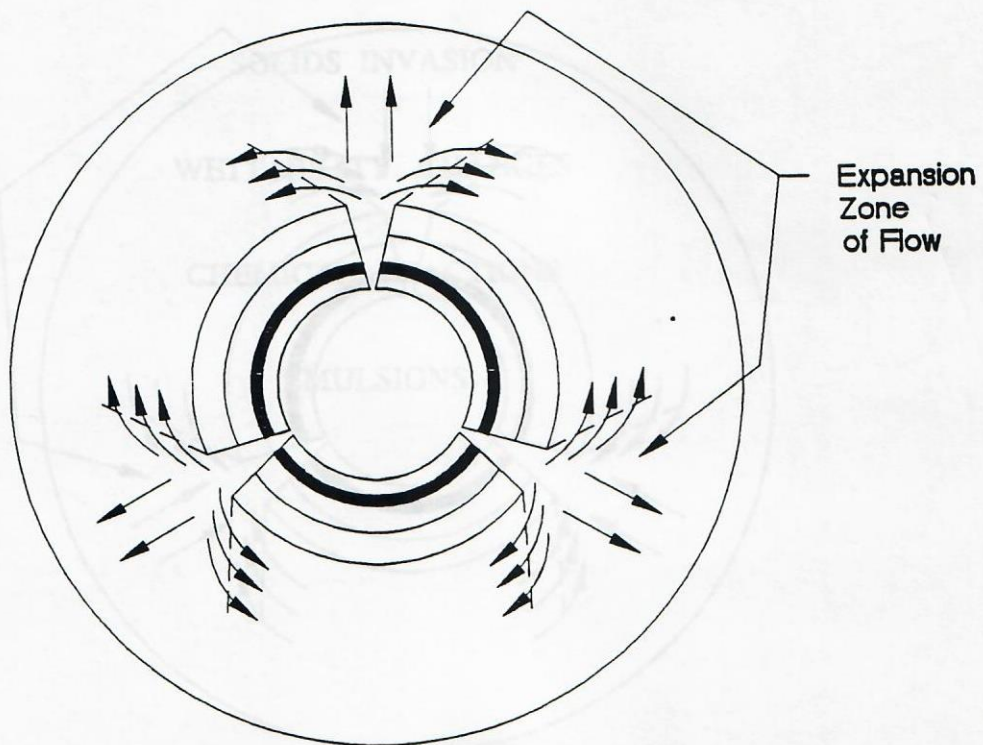


PERFORATION WASHING

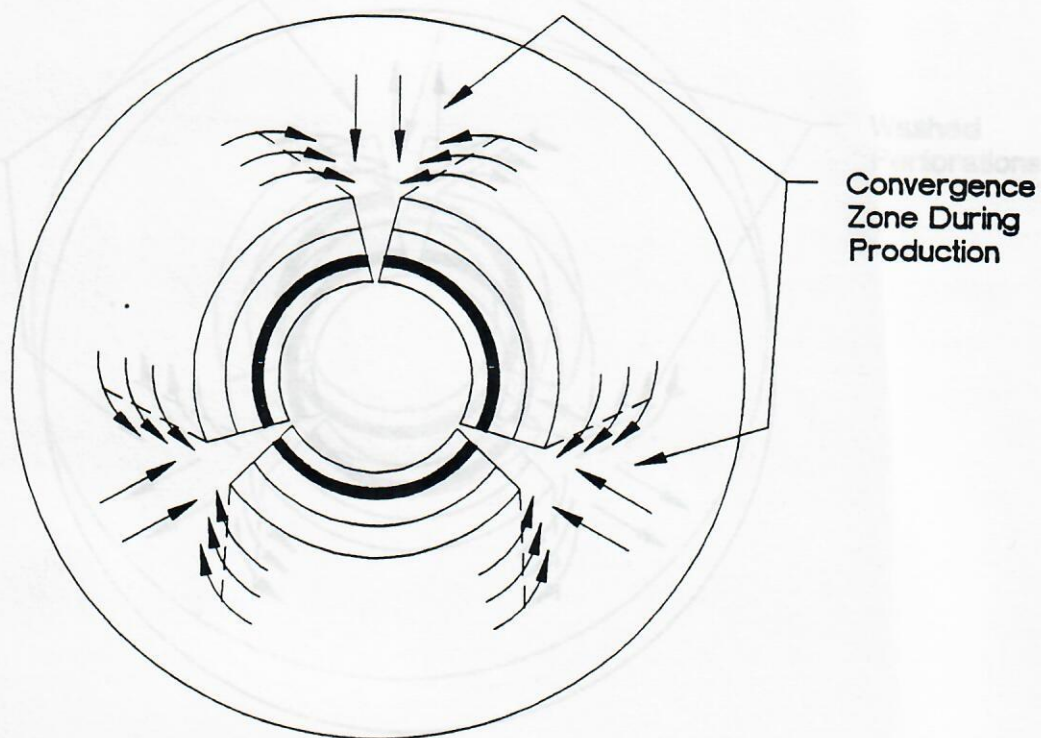


TYPES OF FORMATION DAMAGE

ZONE OF POTENTIAL DAMAGE



PERFORATION WASHING ZONE OF CONVERGENCE



TYPES OF FORMATION DAMAGE

SWELLING

DISPERSION

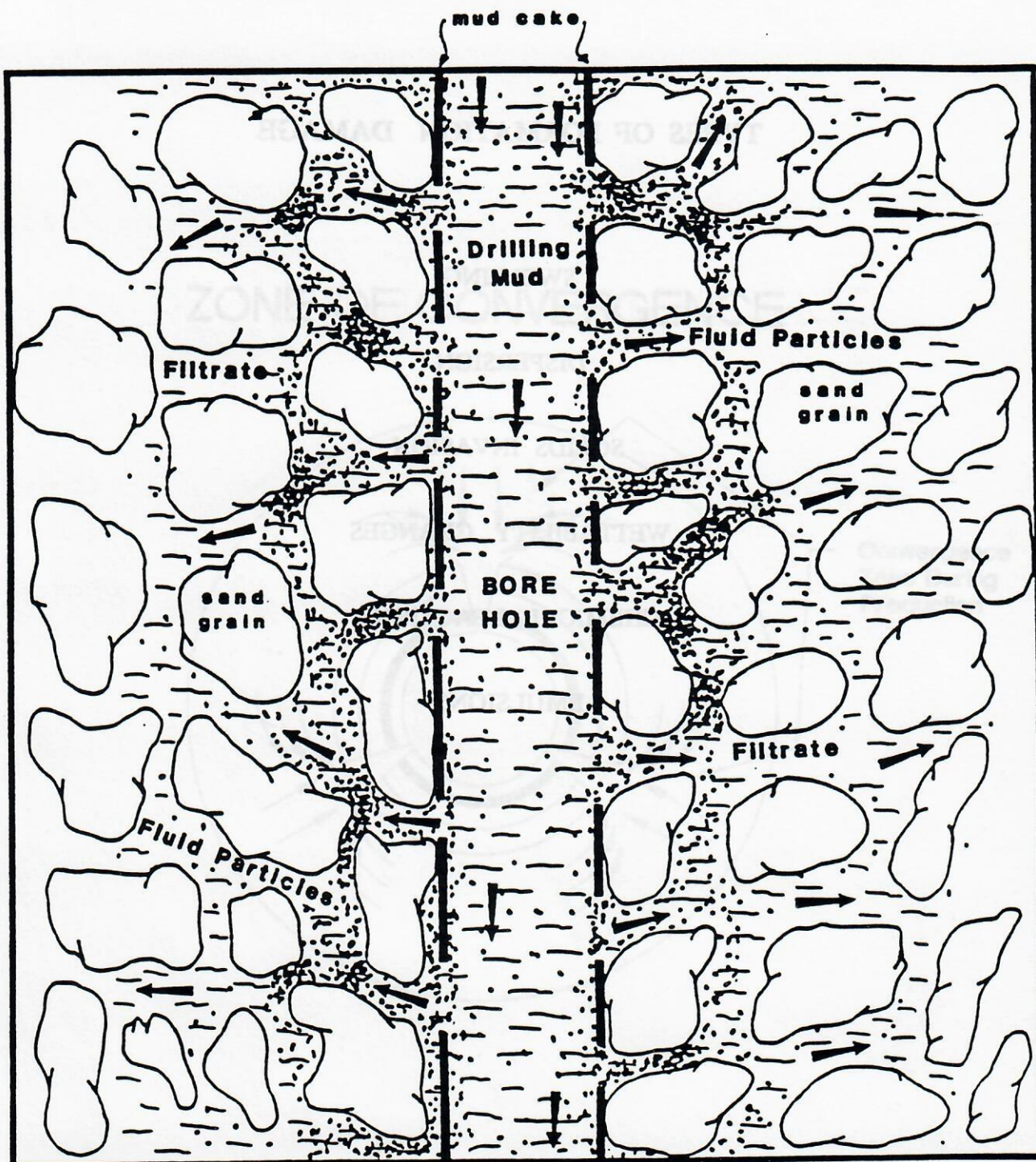
SOLIDS INVASION

WETTABILITY CHANGES

CHEMICAL REACTIONS

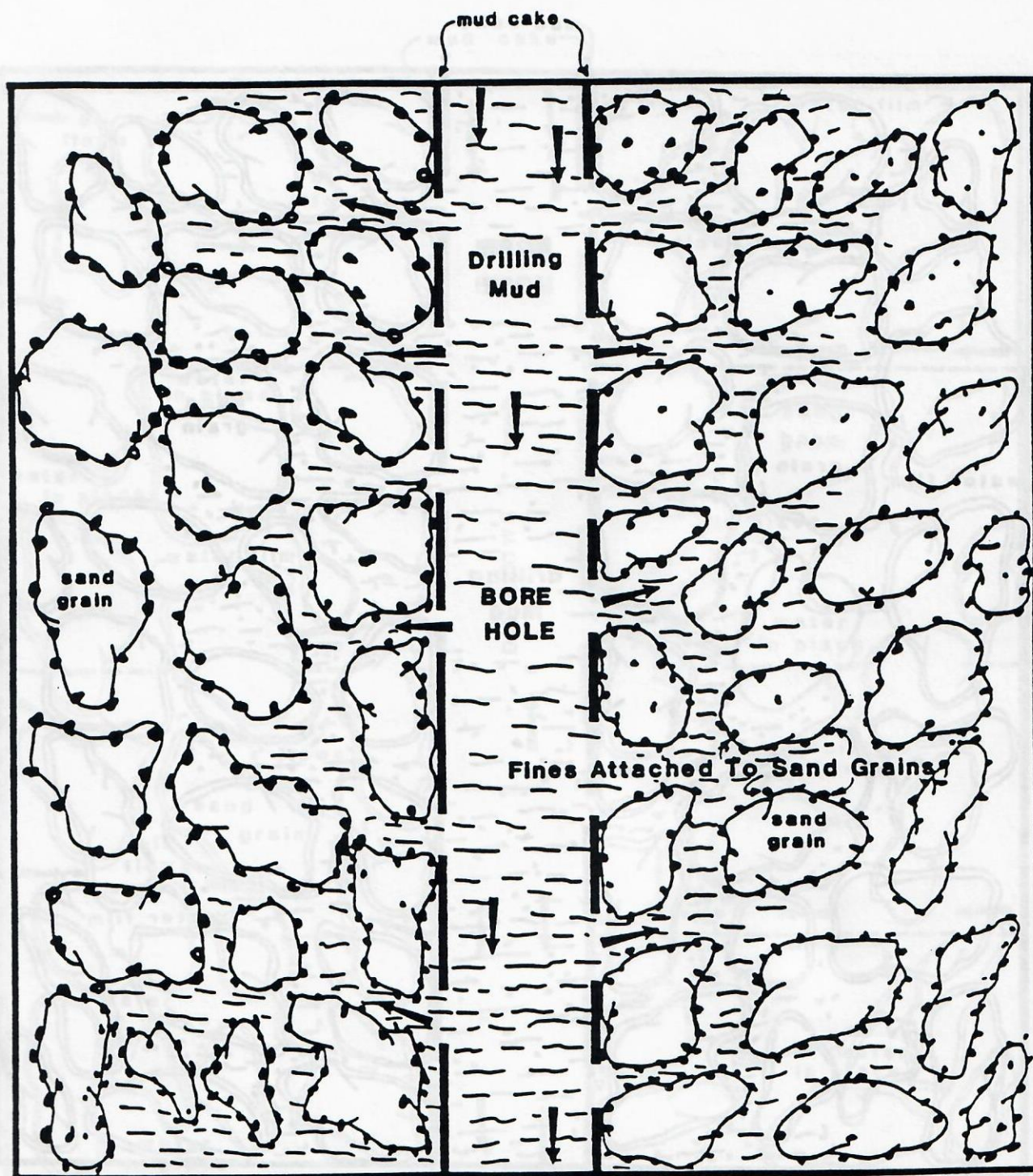
EMULSIONS

VERTICAL CROSS SECTION OF A BORE HOLE
LEAKAGE OF MUD PARTICLES AND FILTRATE FROM DRILLING MUD GOING
INTO THE FORMATION, DECREASING PERMEABILITY
AND CAUSING FORMATION DAMAGE



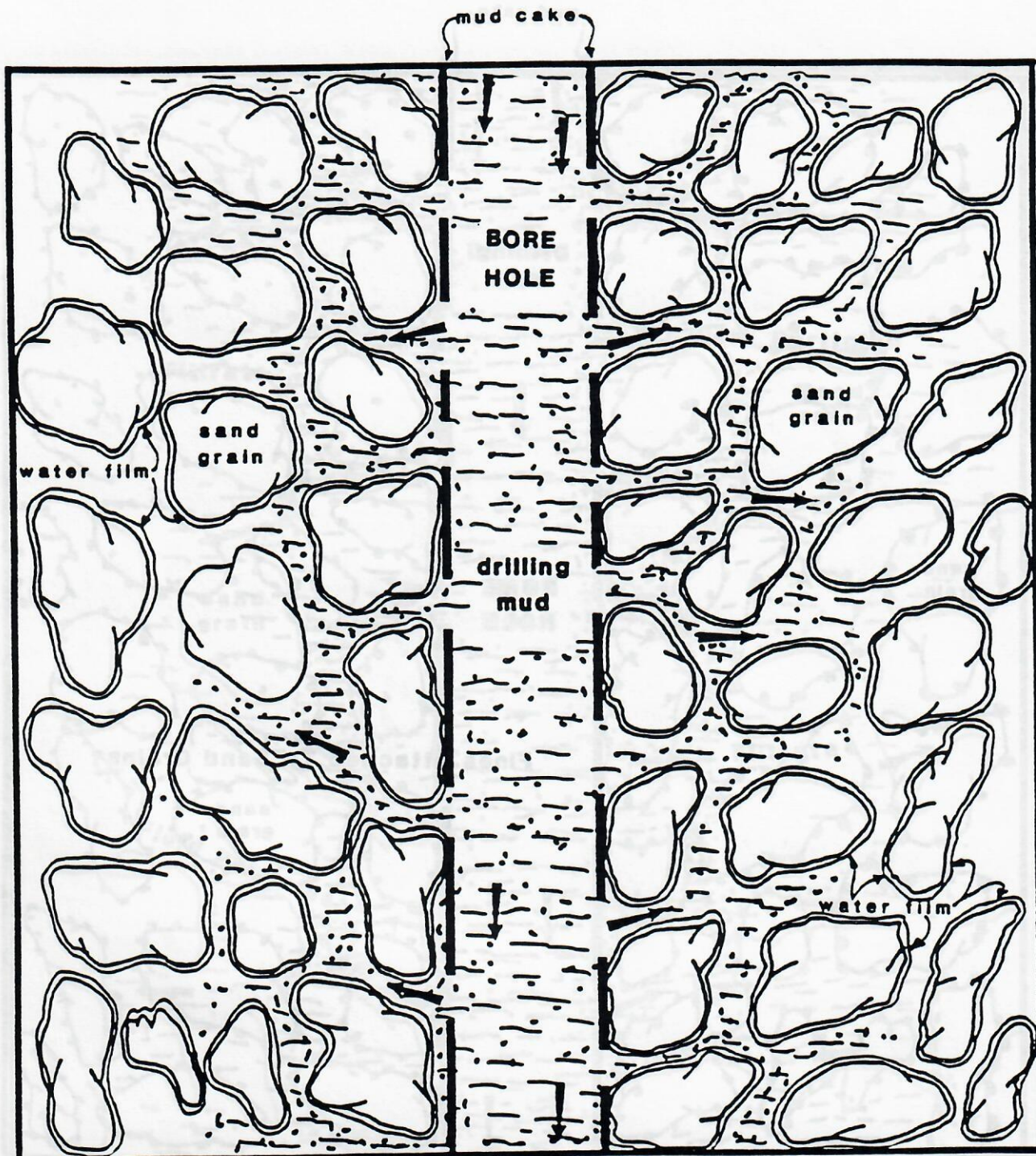
VERTICAL CROSS SECTION OF A BORE HOLE

Illustration of mud particles and filtrate from drilling mud going into the formation, blocking POROSITY and diminishing PERMEABILITY



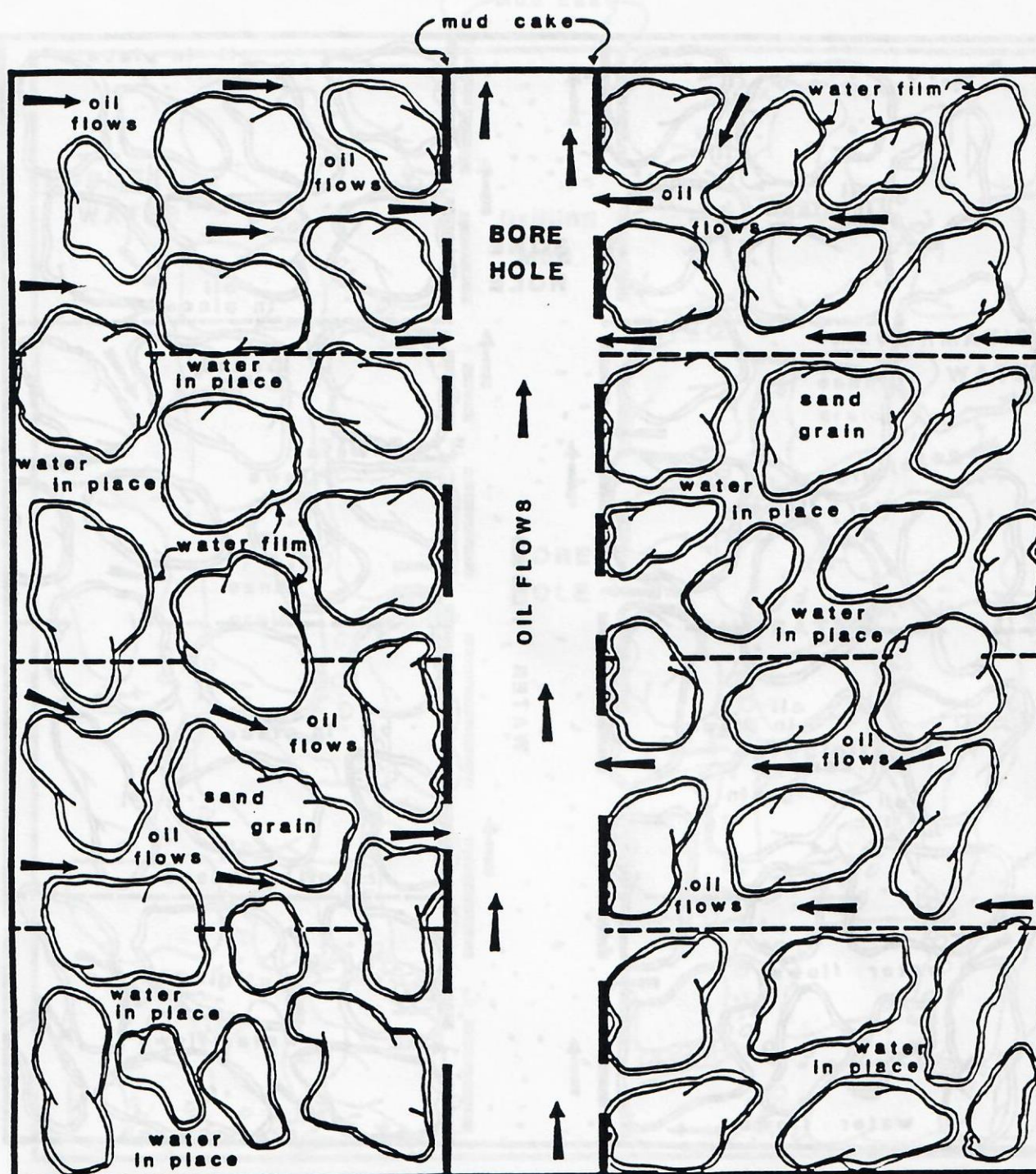
VERTICAL CROSS SECTION OF A BORE HOLE

Illustration of how FINES are attached to sand grains



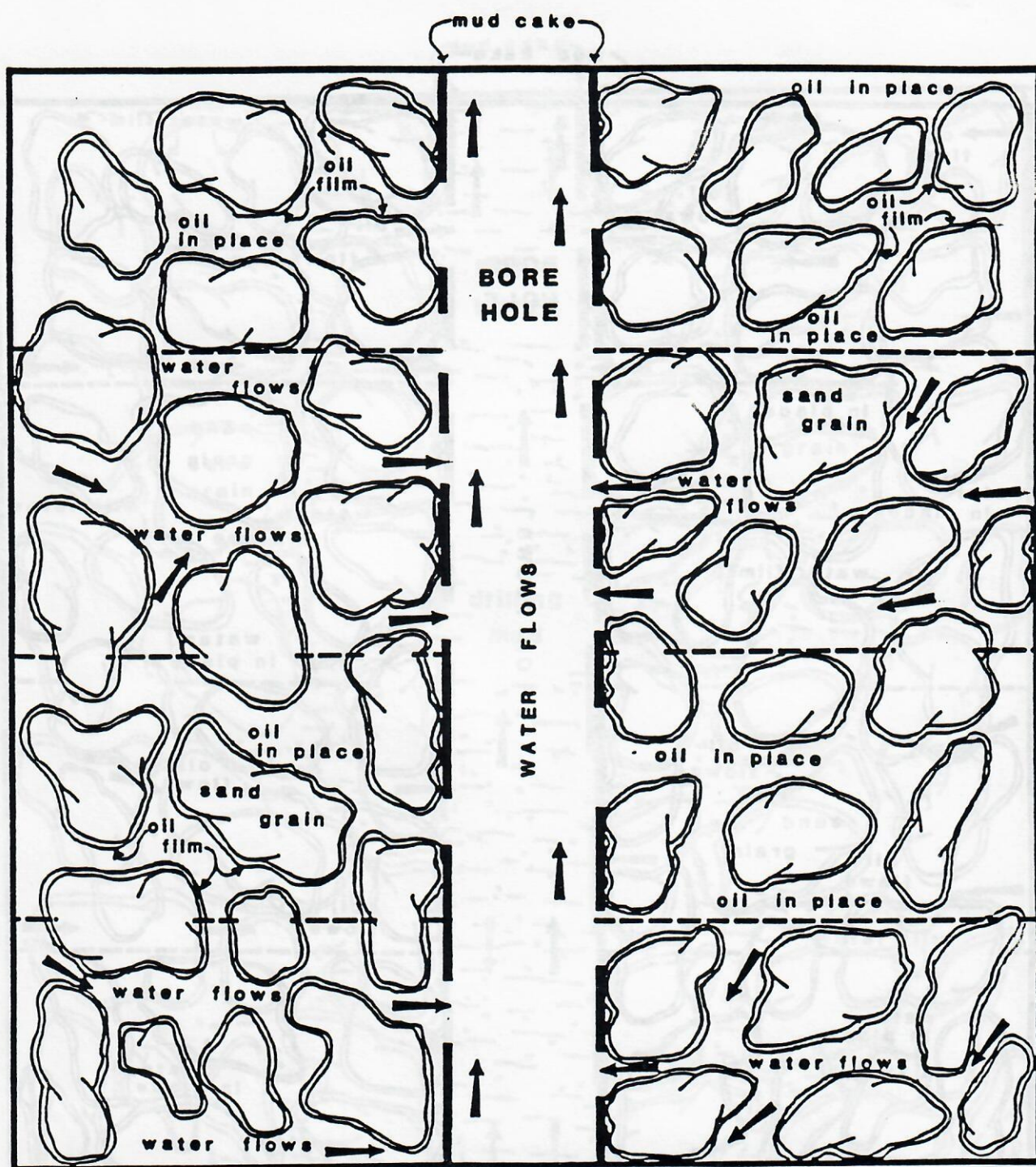
VERTICAL CROSS SECTION OF A BORE HOLE

Illustration of a formation with natural state of WATER WET sand grains



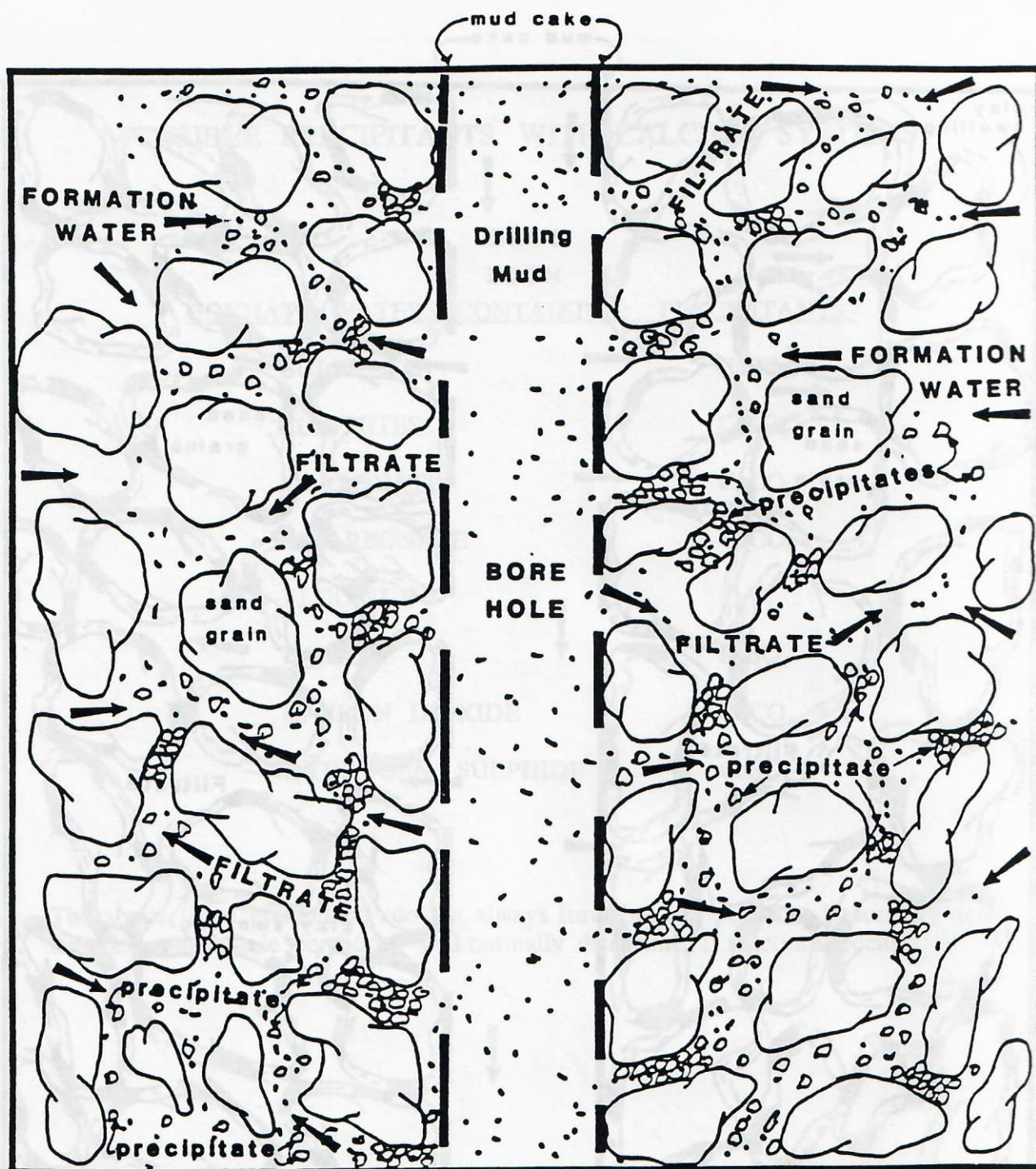
VERTICAL CROSS SECTION OF A BORE HOLE

Illustration of an OIL PRODUCING FORMATION when
there are WATER WET sand grains



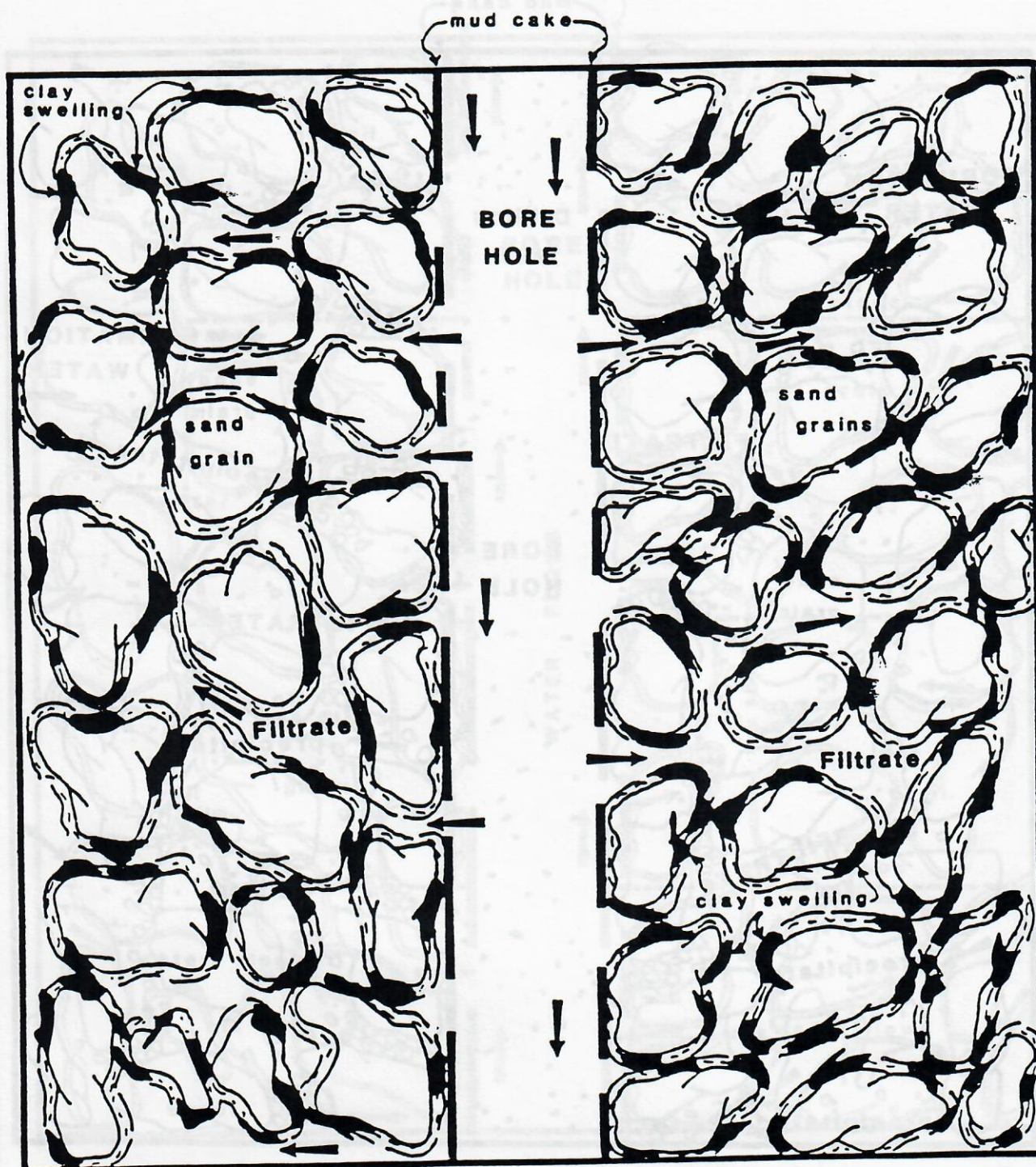
VERTICAL CROSS SECTION OF A BORE HOLE

Illustration of a WATER PRODUCING FORMATION when
there are OIL WET sand grains



VERTICAL CROSS SECTION OF A BORE HOLE

Precipitate Blocking from Interaction of Formation Water and Filtrate



VERTICAL CROSS SECTION OF A BORE HOLE

Types of Clay Swelling :

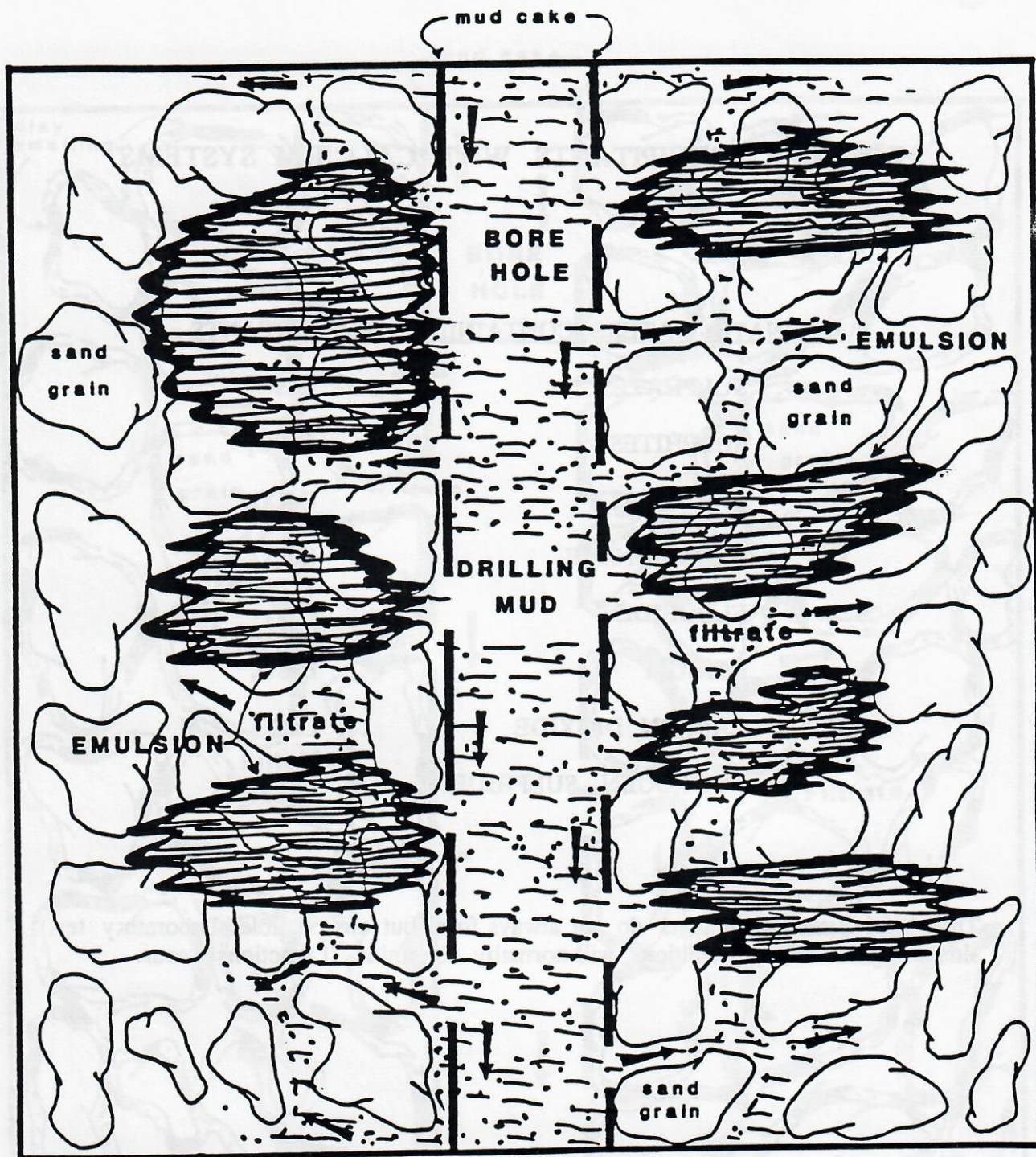
CRYSTALLINE and OSMOTIC

POSSIBLE PRECIPITANTS WITH CALCIUM SYSTEMS

CONNATE WATERS CONTAINING: PRECIPITANTS

SULPHATES	CaSO_4
SULPHITES	CaSO_4
CARBONATE	CaCO_3
BICARBONATE	CaCO_3
FLUORIDE	CaF_2
BARIUM	BaSO_4
CARBON DIOXIDE	CaCO_3
HYDROGEN SULPHIDE	CaSO_4

The above listed precipitants do not always form but are possible. Laboratory test simulating downhole conditions will normally determine if reactions occur.



VERTICAL CROSS SECTION OF A BORE HOLE

Illustration of Formation Damage
by

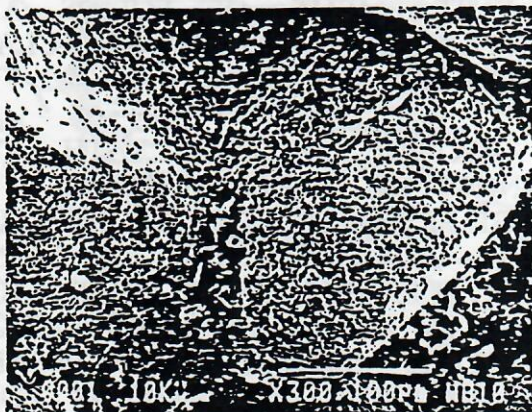
Emulsion of two or more incompatible fluids

PERMEABILITY IMPAIRMENT BY INDIGENOUS CLAYS

IT IS APPARENT THAT THE FLUIDS MOVING THROUGH THE PORES ENCOUNTER SOME VERY CRITICAL CONDITIONS - TORTUOUS PATHS; ROUGH PORE WALLS WITH LARGE SURFACE AREA; AND A VARIETY OF REACTIVE MINERALS SUCH AS CLAYS, FELDSPARS, MICAS, AND IRON COMPOUNDS. THESE PORE CONDITIONS PROVIDE AN IDEAL MEDIUM FOR BOTH PHYSICAL ENTRAPMENT OF SOLIDS AND CHEMICAL REACTIONS BETWEEN INVADING FLUIDS AND THE CLAYS OR OTHER MINERALS LINING THE PORES.

ALONG WITH THE PHYSICAL NATURE OF THE PATH, THE MINERALOGICAL COMPOSITION CANNOT BE OVEREMPHASIZED. FOR MANY YEARS, PERMEABILITY DAMAGE FROM FRESHWATER INVASION WAS ASSUMED TO BE ASSOCIATED WITH SWELLING OF MONT-MORILLONITE BY FRESH WATER. NOW, IT IS WELL ESTABLISHED THAT LOW OR NONSWELLING MINERALS CAN ALSO CAUSE FORMATION DAMAGE, AND FRESHWATER CONTACT IS NOT A NECESSARY CONDITION. SALINITY CHANGES AND SHEAR BY MOVING PORE WATER MAY TRIGGER THE RELEASE OF WEAKLY BONDED CLAYS, MICA, FELDSPAR, AND OTHER MINERALS FROM PORE WALLS. THE RELEASED PARTICLES WILL THEN FLOW WITH THE WATER, BRIDGING AT PORE CONSTRICTIONS. FOR EXAMPLE, REED HAS SHOWN THAT WHEN MICA IN THE FORMATION PORES IS NOT IN EQUILIBRIUM WITH INVADING WATER, THAT MICA MAY BREAK UP WHEN ION EXCHANGE OCCURS.

SOME OF THE FIRST INDICATIONS OF PARTICLE MOVEMENT OBSERVED IN THE LABORATORY WERE (1) ABRUPT CHANGES IN PERMEABILITY VALUES WHEN FLOW THROUGH A CORE WAS REVERSED ("CHECK VALVE PLUGGING"). (2) THE DISCHARGE OF MICRON-SIZED FINES WHEN FRESH WATER WAS INJECTED INTO A CLAY-CONTAINING CORE, AND (3) LOWER PERMEABILITIES TO WATER IN SINGLE-PHASE FLOW THAN PERMEABILITIES TO OIL IN RESTORED-STATE FLOW IN WATER-SENSITIVE CORES. FOR MANY YEARS, THE SIGNIFICANCE OF THESE OBSERVATIONS WAS NOT WIDELY RECOGNIZED. HOWEVER, CONTINUING RESEARCH ON FORMATION DAMAGE DURING DRILLING LED TO AN UNEXPECTED OBSERVATION THAT EMPHASIZED THE IMPORTANCE OF PARTICLE MOVEMENT.



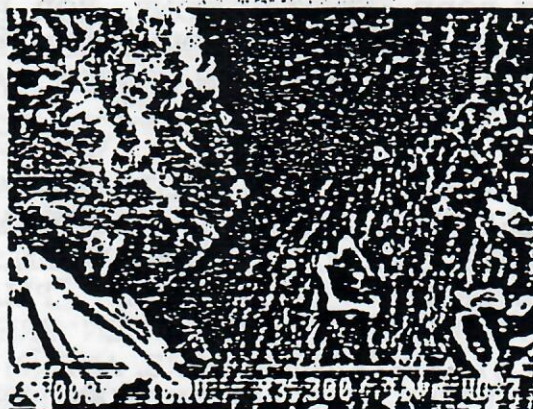
PHOTOMICROGRAPH of freshly cut Aramco core (Fig. 1).



PHOTOMICROGRAPH of freshly cut Albahji core (Fig. 2).



PHOTOMICROGRAPH of Aramco core after displacement runs (Fig. 3).



PHOTOMICROGRAPH of Albahji core after displacement runs (Fig. 4).

48 Oil & Gas Journal, Dec 10, 1990

VERTICAL CROSS SECTION OF A BORE HOLE

Illustration of Formation Damage Caused by Emulsion

by

Emulsion of two or more immiscible fluids

PERMEABILITY IMPAIRMENT BY INDIGENOUS CLAYS

DETRITAL CLAYS - SEDIMENTED

DIAGENETIC CLAYS - PRECIPITATED FROM FORMATION WATERS
INTERACTION OF FORMATION WATER AND
PRE-EXISTING CLAY MINERALS

CLAYS CAN BE PRESENT AS:

- PART OF A MATRIX - AS COATING ON PORE WALLS
- LYING LOOSE IN THE PORES

DIAGENETIC CLAYS USUALLY OCCUR AS A DEPOSIT OF CLAY
PLATELETS ON THE PORE WALLS ORIENTED NORMALLY TO THE
GRAIN SURFACES. ALSO PRESENT IN THIN LAYERS, OR PARTINGS,
IN THE SAND BEDS.

CARBONATE FORMATIONS ARE SELDOM CLAY-BEARING AND WHEN
CLAYS ARE PRESENT THEY ARE INCORPORATED IN THE MATRIX.

AQUEOUS FILTRATES CAN SEVERELY DAMAGE PERMEABILITY OF
ROCK DUE TO ACTION ON INDIGENOUS CLAYS.

EXAMPLE: INDIGENOUS MONTMORILLONITE

PERMEABILITY:

60 MD TO AIR

20 MD TO INTERSTITIAL WATER (SAME FORMATION)

BRINE - PERMEABILITY DECREASED WITH SALINITY DECREASE

0.002 - DISTILLED WATER

PERMEABILITY REDUCED DUE TO:

1. SWELLING OF CLAY
2. DISPERSION OF CLAY
3. BLOCKING OF PORES DUE TO MIGRATION OF PARTICLES

SOME TEST SHOW THAT PERMEABILITY REDUCTION IS GREATEST WHEN MONTMORILLONITE AND MIXED-LAYER CLAYS ARE PRESENT. REDUCTION IS LESS WITH ILLITE. LEAST WITH KAOLINITE AND CHLORITE.

PERMEABILITY IMPAIRMENT BY LOOSE FINES OF MINERALS

MICA

QUARTZ

EXAMPLE: UNCONSOLIDATED GULF COAST SANDS CONSIST OF FINES*

39% QUARTZ

32% AMORPHOUS MATERIALS

12% CLAYS

* THE FINES WERE LOCATED ON THE LARGER GRAINS

INDIGENOUS CLAYS (Continued)

MECHANICS OF IMPAIRMENT BY INDIGENOUS CLAYS

ONE TEST PROCEDURE

FLOW SATURATED NaCl THROUGH CORE OR SANDPACK
FLOW WITH TEST FLUID
DETERMINE DIFFERENCE IN PERMEABILITY

TYPES OF REDUCTION IN PERMEABILITY

CRYSTALLINE SWELLING

DISPERSION

SALINITY RANGE OF EACH PHENOMENA

DEFLOCCULATION

AT LESS THAN 20 g/l OF NaCl CLAYS BECOME "UNSTABLE" (i.e. DISPERSED)

DISPERSED - BORDEN AND JACQUIN

EXPANSION OF LATTICE SPACING - NORRISH

CHANGE FROM AGGREGATION TO DISPERSION

TEST - DISTILLED WATER THROUGH PACK

10% MONTMORILLONITE - PLUGGED PACK COMPLETELY

5% MONTMORILLONITE - PERMEABILITY INCREASED AND CLAY
WAS DISCHARGED FROM END OF
PACK*

* AT SALINITIES BELOW ABOUT 1 g/l CLAY PARTICLES ARE
DEFLOCCULATED AS WELL AS DISPERSED, AND ARE MUCH
MORE MOBILE THAN WHEN FLOCCULATED: DISPERSED.

CRYSTALLINE SWELLING CAUSES THE CLAY VOLUME TO NO MORE
THAN DOUBLE. IF PRESENT ON PORE WALLS IT HAS LITTLE EFFECT
ON PERMEABILITY DUE TO SWELLING. BUT THE DEFLOCCULATED
AND DISPERSED CLAY PARTICLES ARE USUALLY TRAPPED IN THE
TORTUOUS FLOW PATHS AND THERE IS A SHARP DROP IN
PERMEABILITY. CALLED "CLAY BLOCKING".

DEFLOCCULANTS SUCH AS SODIUM HEXAMETAPHOSPHATE RAISE THE FLOCCULATION POINT OF MONTMORILLONITE IN NaCl TO 20 G/L SO THAT PARTICLES ARE BOTH DEFLOCCULATED AND DISPERSED AT LOWER SALINITIES. THEREFORE PERMEABILITIES ARE LOWER. NO COMPLEX PHOSPHATE OR TANNATES SHOULD EVER BE ADDED TO DISPERSE MUDS WHEN DRILLING THROUGH WATER SENSITIVE FORMATIONS.

RATE OF REDUCTION OF SALINITY AFFECTS CLAY BLOCKING. LESS BLOCKING IF SALINITY IS REDUCED GRADUALLY.

EXAMPLE:

190 MD - TO LESS THAN 1 MD, IF NaCl REDUCED FROM 30,000 PPM TO 0, IN 1.2 PORE VOLUMES. SUDDEN CHANGE IN ELECTROCHEMICAL ENVIRONMENT PROMOTED DISPERSION OF THE PARTICLES.

CLAY MINERALS ORIGINATE FROM DEGRATION OF IGNEOUS ROCK IN SITU. THE PARENT MINERALS ARE THE MICAS, FELDSPARS ($(\text{CaO}, \text{K}_2\text{O}) \text{Al}_2 \text{O}_3 \cdot 6\text{SiO}_2$) AND FERROMAGNESIUM MINERALS SUCH AS HORNBLENDE ($(\text{Ca}, \text{Na})_2 (\text{Mg}, \text{Fe}, \text{Al})_5 (\text{Al}, \text{Si})_3 \text{O}_{22} (\text{OH}, \text{F})_2$) BENTONITE IS FORMED BY THE WEATHERING OF VOLCANIC ASH.

WEATHERING: CLIMATE, TOPOGRAPHY, VEGETATION AND TIME EXPOSURE. RAINFALL PERCOLATING THROUGH SOIL AND SOIL pH.
pH FROM PARENT ROCK, CO_2 IN ATMOSPHERE AND VEGETATION. SILICA LEACHED BY ALKALINE CONDITIONS. ALUMINA AND FERRIC OXIDE LEACHED BY ACID CONDITIONS.

CLAYS FORMED IN SITU ARE PRIMARY CLAYS.

SECONDARY CLAYS ARE CLAYS CARRIED DOWN STREAM AND DEPOSITED ON FRESH WATER OR MARINE ENVIRONMENTS.

MONTMORILLONITE IS ABUNDANT IN TERTIARY AND LESS COMMON IN MESOZOIC, AND RARE BELOW THAT.

CHLORITE AND ILLITE MOST ABUNDANT OF CLAY MINERALS AND ARE FOUND IN ALL AGES OF SEDIMENTS.

KAOLINITE IS PRESENT IN YOUNG AND OLD IN SMALL AMOUNTS.

WY. BENTONITE 85% MONTMORILLONITE, Na, Ca, Mg, MOST COMMON BASE EXCHANGE IONS.

DEFLOCCULATION AND DISPERSION

MANY CLAYS ENCOUNTERED IN DRILLING ARE PREDOMINATELY CALCIUM AND MAGNESIUM CLAYS, AND HENCE ARE AGGREGATED. WHEN TREATED WITH THINNER, BOTH DEFLOCCULATION AND DISPERSION OCCUR SIMULTANEOUSLY - DEFLOCCULATION BECAUSE OF THE ACTION OF THE ANION, AND DISPERSION BECAUSE OF THE CONVERSION OF THE CLAY TO THE SODIUM FORM. DISPERSION IS UNDESIRABLE BECAUSE IT INCREASES THE PLASTIC VISCOSITY. DISPERSION MAY BE AVOIDED BY SIMULTANEOUS ADDITION OF A POLYVALENT SALT OR HYDROXIDE WITH THE THINNER.

FLOCCULATION POWER ON MONOVALENT SALTS

$Cs > Rb > NH_4 > K > Na > Li$

HOFFMEISTER SERIES OR LYOTROPIC SERIES

CLAY SWELLING MECHANISMS

TWO: CRYSTALLINE AND OSMOTIC

CRYSTALLINE SWELLING (SURFACE HYDRATION) ADSORPTION OF LAYERS OF WATER ON THE BASAL CRYSTAL SURFACES WITH EACH SUCCEEDING LAYER THE BOND BECOMES WEAKER. (STRUCTURED WATER FOR 75 - 100 Å).

Na CLAY - ADSORBS 0.5 g H₂O PER 1.0 g CLAY = DOUBLE VOLUME

OSMOTIC SWELLING BECAUSE THE CONCENTRATION OF CATIONS IS GREATER BETWEEN THE LAYERS THAN IN THE BULK SOLUTION. THEREFORE WATER IS DRAWN BETWEEN THE LAYERS, THEREBY INCREASING THE C-SPACING.

Na CLAY - ADSORBS 10 g H₂O PER 1.0 g CLAY = 20 FOLD VOLUME GAIN. IN DISTILLED WATER AGGREGATES SUB-DIVIDE AND AUTO-DISPERSE INTO ENTER BODY LIQUID.

EFFECT OF BASE EXCHANGE REACTIONS ON CLAY BLOCKING

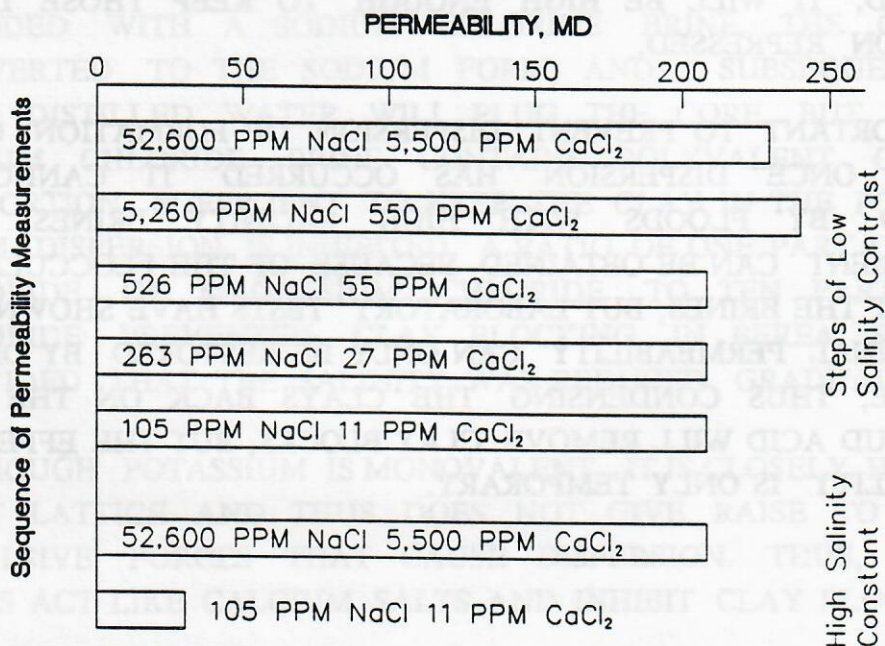
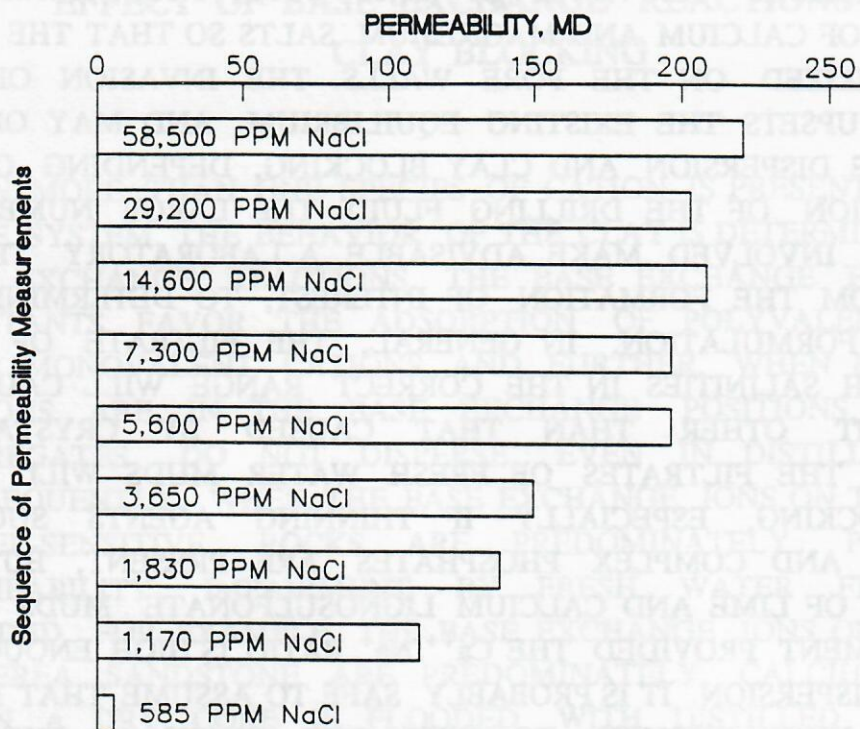
WHEN MORE THAN ONE SPECIES OF CATION IS PRESENT IN A CLAY-BRINE SYSTEM, THE BEHAVIOR OF THE CLAY IS DETERMINED BY THE BASE EXCHANGE REACTIONS. THE BASE EXCHANGE EQUILIBRIUM CONSTANTS FAVOR THE ADSORPTION OF POLYVALENT CATIONS OVER MONOVALENT CATIONS, AND, FURTHER, WHEN POLYVALENT CATIONS ARE IN THE BASE EXCHANGE POSITIONS, THE CLAY AGGREGATES DO NOT DISPERSE, EVEN IN DISTILLED WATER. CONSEQUENTLY, WHEN THE BASE EXCHANGE IONS ON THE CLAYS IN WATER-SENSITIVE ROCKS ARE PREDOMINATELY POLYVALENT, PERMEABILITY IMPAIRMENT BY FRESH WATER FILTRATES IS AVOIDED. FOR EXAMPLE, THE BASE EXCHANGE IONS ON THE CLAYS IN BEREA SANDSTONE ARE PREDOMINATELY CALCIUM, SO THAT WHEN A DRY CORE IS FLOODED WITH DISTILLED WATER, NO IMPAIRMENT IS OBSERVED. IF, HOWEVER, THE DRY CORE IS FIRST FLOODED WITH A SODIUM CHLORIDE BRINE, THE CLAYS ARE CONVERTED TO THE SODIUM FORM, AND A SUBSEQUENT FLOOD WITH DISTILLED WATER WILL PLUG THE CORE. BUT WHEN THE SODIUM CHLORIDE BRINE CONTAINS POLYVALENT CATIONS IN PROPORTION SUFFICIENT TO KEEP THE CLAY IN THE POLYVALENT FORM, DISPERSION IS INHIBITED. A RATIO OF ONE PART OF CALCIUM CHLORIDE OR MAGNESIUM CHLORIDE TO TEN PARTS SODIUM CHLORIDE PREVENTED CLAY BLOCKING IN BEREA SANDSTONE, PROVIDED THAT THE SALINITY WAS REDUCED GRADUALLY.

ALTHOUGH POTASSIUM IS MONOVALENT, IT IS CLOSELY HELD IN THE CLAY LATTICE AND THUS DOES NOT GIVE RAISE TO THE HIGH REPULSIVE FORCES THAT CAUSE DISPERSION. THUS, POTASSIUM SALTS ACT LIKE CALCIUM SALTS AND INHIBIT CLAY BLOCKING.

THE CATIONS IN SUBSURFACE FORMATIONS ARE IN EQUILIBRIUM WITH THOSE IN THE INTERSTITIAL WATER. THE MAJOR CONSTITUENT OF FORMATION BRINES IS NORMALLY SODIUM CHLORIDE IN

CONCENTRATIONS ABOVE 20 g/l (20,000 PPM), PLUS SIGNIFICANT AMOUNTS OF CALCIUM AND MAGNESIUM SALTS SO THAT THE CLAYS ARE STABILIZED ON THE PORE WALLS. THE INVASION OF MUD FILTRATE UPSETS THE EXISTING EQUILIBRIUM AND MAY OR MAY NOT CAUSE DISPERSION AND CLAY BLOCKING, DEPENDING ON THE FORMULATION OF THE DRILLING FLUID. THE LARGE NUMBER OF VARIABLES INVOLVED MAKE ADVISABLE A LABORATORY TEST ON CORES FROM THE FORMATION OF INTEREST, TO DETERMINE THE OPTIMUM FORMULATION. IN GENERAL, THE FILTRATE OF BRINE MUDS WITH SALINITIES IN THE CORRECT RANGE WILL CAUSE NO IMPAIRMENT OTHER THAN THAT CAUSED BY CRYSTALLINE SWELLING. THE FILTRATES OF FRESH WATER MUDS WILL CAUSE CLAY BLOCKING, ESPECIALLY IF THINNING AGENTS SUCH AS TANNATES AND COMPLEX PHOSPHATES ARE PRESENT, BUT THE FILTRATES OF LIME AND CALCIUM LIGNOSULFONATE MUDS CAUSE NO IMPAIRMENT PROVIDED THE $\text{Ca}^{++}/\text{Na}^{+}$ RATIO IS HIGH ENOUGH TO REPRESS DISPERSION. IT IS PROBABLY SAFE TO ASSUME THAT IF THIS RATIO IS HIGH ENOUGH TO KEEP THE CLAYS IN THE MUD REPRESSED, IT WILL BE HIGH ENOUGH TO KEEP THOSE IN THE FORMATION REPRESSED.

IT IS IMPORTANT TO PREVENT DISPERSION OF FORMATION CLAYS, BECAUSE ONCE DISPERSION HAS OCCURRED IT CANNOT BE REVERSED BY FLOODS WITH HIGH SALINITY BRINES. SOME IMPROVEMENT CAN BE OBTAINED BECAUSE OF THE FLOCCULATING ACTION OF THE BRINES, BUT LABORATORY TESTS HAVE SHOWN THAT THE ORIGINAL PERMEABILITY CAN ONLY BE RESTORED BY DRYING THE CORE, THUS CONDENSING THE CLAYS BACK ON THE PORE WALLS. MUD ACID WILL REMOVE CLAY BLOCKS, BUT THE EFFECT ON PERMEABILITY IS ONLY TEMPORARY.



Decrease in permeability with decrease in salinity.

- a. Brine contains sodium chloride only
- b. Brine contains one part calcium chloride to ten parts sodium chloride

PERMEABILITY REDUCTION OF BEREA WITH CONTINUOUS SALINITY DECREASE*

TIME** (HR)	SALINITY (ppm)	PERMEABILITY (MD)	SALINITY (ppm)	PERMEABILITY (MD)
0	C ₀ = 30,000	190	C ₀ = 30,000	190
1	18,200	180	28,500	187
2	11,200	175	27,100	187
4	4,050	170	24,500	188
8	550	100	20,100	188
10	200	50	18,200	187
20	1	25	11,000	186
40			4,050	183
60			1,500	180
80			550	180
100			200	179
150			17	178
210			1	177

* FROM MAUNGAN. COPYRIGHT 1965 BY SPE-AIME.

** INJECTION RATE = 1 PV/HR = 120 CC/HR.

MINIMUM SALINITIES OF BRINES REQUIRED TO PREVENT CLAY BLOCKING IN WATER-SENSITIVE FORMATIONS

SPECIES OF CLAY MINERAL IN THE FORMATION	SODIUM CHLORIDE BRINE (ppm NaCl)	CALCIUM CHLORIDE BRINE (ppm CaCl ₂)	POTASSIUM CHLORIDE BRINE (ppm KCl)
MONTMORILLONITE	30,000	10,000	10,000
ILLITE, KAOLINITE, CHLORITE	10,000	1,000	1,000

EXCHANGE IONS

CATIONS ARE ABSORBED ON THE BASAL SURFACES TO COMPENSATE FOR ATOMIC SUBSTITUTION IN THE CRYSTAL STRUCTURE. BASE EXCHANGE CAPACITY IS THE TOTAL AMOUNT OF CATIONS ABSORBED. WHEN IONS OF DIFFERENT VALENCES ARE PRESENT, THE ONE WITH THE HIGHER VALENCE IS GENERALLY ABSORBED PREFERENTIALLY.



THE EFFECT OF pH

CLAY DISPERSION IS INFLUENCED BY pH BECAUSE IT AFFECTS THE BASE EXCHANGE EQUILIBRIUM, BUT ITS EFFECT ON A PARTICULAR SYSTEM DEPENDS ON THE ELECTRO-CHEMICAL CONDITIONS IN THAT SYSTEM. THE pH OF THE FILTRATE MAY BE THE CAUSE OF IMPAIRMENT BY ANOTHER MECHANISM IF THE MATRIX CEMENT IS AMORPHOUS SILICA. FILTRATES WITH A VERY HIGH pH DISSOLVE THE SILICA, RELEASING FINE PARTICLES, WHICH MAY THEN BLOCK THE PORES.

ELECTROSTATIC DOUBLE LAYER

PARTICLES IN COLLOIDAL SUSPENSION CARRY A SURFACE CHARGE. THIS CHARGE ATTRACTS IONS OF THE OPPOSITE SIGN, WHICH ARE CALLED COUNTER IONS. THIS COMBINATION IS CALLED THE ELECTROSTATIC DOUBLE LAYER.

THE DISTRIBUTION OF IONS IN THE DOUBLE LAYER RESULTS IN A POTENTIAL GRADING FROM A MAXIMUM AT THE PARTICLE SURFACE TO ZERO IN THE BULK SOLUTION.

ZETA POTENTIAL IS MAXIMUM, AND THE MOBILE LAYER IS MOST DIFFUSED WHEN THE BULK SOLUTION IS PURE WATER.

ELECTROLYTES IN A SOLUTION COMPRESS THE DIFFUSE LAYER AND REDUCE THE ZETA POTENTIAL.

ZETA POTENTIAL DECREASES WITH INCREASE IN VALENCE OF ADDED CATIONS. IF LOW VALENCE IONS ARE REPLACED WITH HIGHER VALENCE ONES THRU BASE EXCHANGE THE ZETA POTENTIAL GREATLY DECREASES.

(RATIO 1 TO 10 TO 500 FOR MORE VALENT, DIVALENT AND TRIVALENT CATIONS RESPECTIVELY).

ZETA POTENTIAL IS ALSO REDUCED BY THE ADSORPTION OF CERTAIN LONG-CHAIN ORGANIC CATIONS.

IT IS POSSIBLE TO NEUTRALIZE AND REVERSE THE ZETA POTENTIAL.

THE POTENTIAL DIFFERENCE BETWEEN THE SURFACE OF A PARTICLE AND THE BULK SOLUTION IS KNOWN AS THE NERNST POTENTIAL. THIS POTENTIAL IS INDEPENDENT OF THE ELECTROLYTES IN SOLUTION.

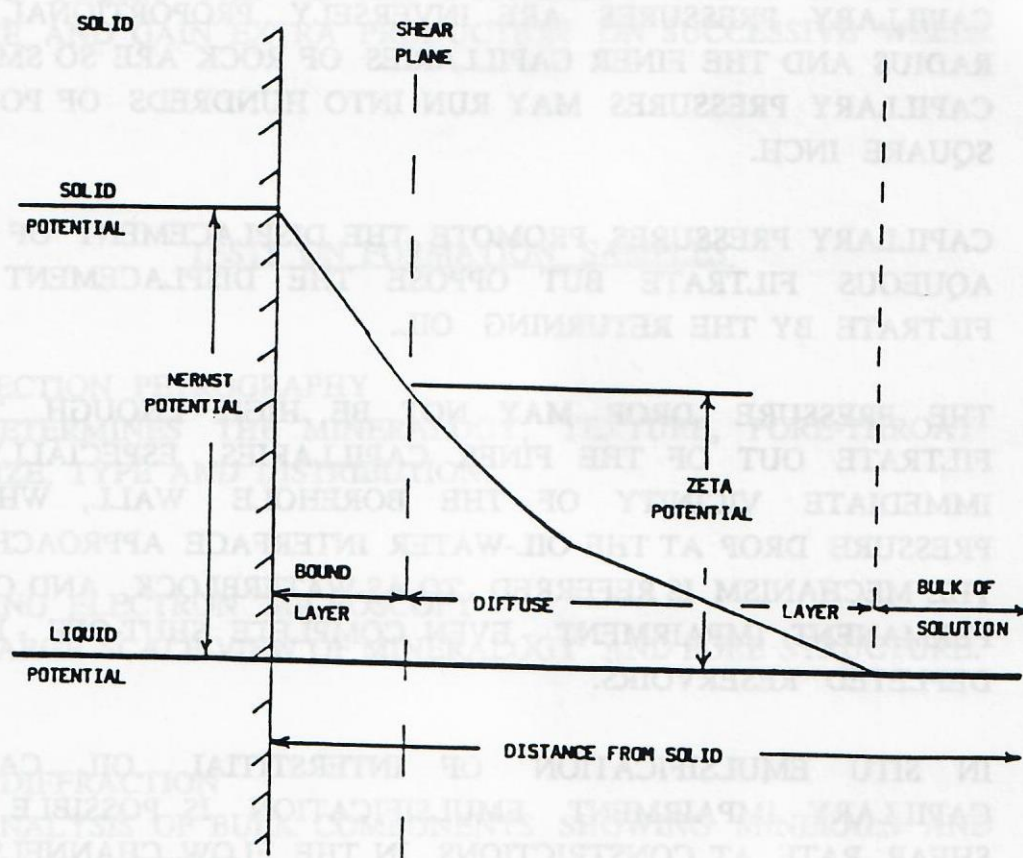


DIAGRAM ILLUSTRATING THE ZETA POSITION (FROM ENGELMANN, TERICHOW, AND SELIM)

CAPILLARY PHENOMENA

CAPILLARY PRESSURES ARE INVERSELY PROPORTIONAL TO THE RADIUS AND THE FINER CAPILLARIES OF ROCK ARE SO SMALL THAT CAPILLARY PRESSURES MAY RUN INTO HUNDREDS OF POUNDS PER SQUARE INCH.

CAPILLARY PRESSURES PROMOTE THE DISPLACEMENT OF OIL BY AN AQUEOUS FILTRATE BUT OPPOSE THE DISPLACEMENT OF THE FILTRATE BY THE RETURNING OIL.

THE PRESSURE DROP MAY NOT BE HIGH ENOUGH TO DRIVE FILTRATE OUT OF THE FINER CAPILLARIES, ESPECIALLY IN THE IMMEDIATE VICINITY OF THE BOREHOLE WALL, WHERE THE PRESSURE DROP AT THE OIL-WATER INTERFACE APPROACHES ZERO. THE MECHANISM IS REFERRED TO AS WATERBLOCK, AND CAN CAUSE PERMANENT IMPAIRMENT - EVEN COMPLETE SHUT-OFF - IN HIGHLY DEPLETED RESERVOIRS.

IN SITU EMULSIFICATION OF INTERSTITIAL OIL CAN CAUSE CAPILLARY IMPAIRMENT. EMULSIFICATION IS POSSIBLE BECAUSE SHEAR RATE AT CONSTRICTIONS IN THE FLOW CHANNELS IS HIGH. STABILIZED EMULSION DROPLETS BECOME TRAPPED IN THE PORES AND REDUCE THE EFFECTIVE PERMEABILITY.

THE FOLLOWING TESTS SHOULD BE RUN ON CORE SAMPLES TO GAIN INSIGHT ON POTENTIAL PROBLEMS THAT MAY BE GENERATED OR PREVENTED BY CHOICE OF FLUIDS. THE MORE THAT IS KNOWN AND UNDERSTOOD ABOUT THE FORMATION AND ITS REACTION WITH VARIOUS FLUIDS THE BETTER POSSIBILITY THERE IS TO AVOID DAMAGE AND GAIN EXTRA PRODUCTION ON SUCCESSIVE WELLS.

TESTS ON FORMATION SAMPLES

THIN SECTION PETROGRAPHY

DETERMINES THE MINERALOGY, TEXTURE, PORE-THROAT SIZE, TYPE AND DISTRIBUTION.

SCANNING ELECTRON MICROSCOPY

LARGE SCALE VIEW OF MINERALOGY AND PORE STRUCTURE.

X-RAY DIFFRACTION

ANALYSIS OF BULK COMPONENTS SHOWING MINERALS AND CLAYS PRESENT.

PERMEAMETER

MEASURES THE PERCENT REGAINED PERMEABILITY AFTER EXPOSURE TO VARIOUS FLUIDS.

CAPILLARY PHENOMENA / WATER BLOCK

Fluid	Surface Tension (dynes/cm) @ 20°C	
Water	72	Strong capillary action
Oil (organics)	20's, 30's, 40's	
Brines (saturated)		
CaCl ₂	18.4	Weak capillary action
KCL	5.5	
NaCl	8.2	
NaBr	3.8	

A liquid will adhere to a solid if the attraction of the molecules to the solid surface is greater than their attraction for each other. That is, the work of adhesion must be greater than the work of cohesion.

Certain corrosion inhibitors, emulsion breakers or cationic surfactants act to oil wet surfaces = oil blocks.

EMULSION BLOCKS are caused by surfactants mixing with oil and water in and around wellbore and can also be caused by high mechanical shearing. EMULSION BREAKERS break interfacial tension between oil and water phases and cause oil droplets to coalesce.

RESERVOIR SENSITIVITY STUDY

INDICATIONS

PARTICLE DISLODGING
MIGRATION OF FINES
HYDRATION OF SWELLING CLAYS
OIL WETTING
OTHER PROBLEMS - SPECIFIC TO PARTICULAR RESERVOIRS

DATA OBTAINED DETERMINES

THRESHOLD VALUES FOR EACH PROBLEM
DEGREE OF DAMAGE
EFFECTIVENESS OF REMEDIAL MEASURES

- ° PORES OCCUPIED BY 2 UNMISCIBLE FLUIDS BOTH WITH CONTINUOUS PHASES CAN TOLERATE CONSIDERABLE FLOW BEFORE MASSIVE SOLID PARTICLE MOVEMENT OCCURS.
- ° LOOSE SOLIDS SMALLER THAN THE PORE OPENINGS CAN BE PRODUCED AS LONG AS FLOWING AS INDIVIDUAL PARTICLES.
- ° IF ONE OR BOTH FLUID PHASES ARE BROKEN A SMALL FLOW RATE CAUSES PLUGGING.

BRINE CORE TEST

1. FLOW NATURAL OR SYNTHETIC FORMATION BRINE THROUGH THE PLUGS UNTIL CONSTANT PERMEABILITY IS OBTAINED.*
2. BACKFLOW OIL (NITROGEN IN THE CASE OF A GAS RESERVOIR) UNTIL CONSTANT PERMEABILITY IS OBTAINED (k_{01}).
3. EXPOSE TO THE TEST FLUID UNDER 500 PSI (35 KG/CM²) DIFFERENT PRESSURE (ASSUMING THE FLUID HAS FILTER-LOSS CONTROL) UNTIL AT LEAST 1 PORE VOLUME OF MUD FILTRATE HAS PASSED THROUGH THE CORE. WITH A THREE-INCH (7.6 CM) PLUG, AN EXPOSURE OF A DAY OR SO MAY THUS BE NECESSARY, UNLESS A DYNAMIC FILTRATION CELL IS USED.
4. BACKFLOW OIL TO CONSTANT PERMEABILITY (k_{02}).

THE CRITERION FOR FORMATION DAMAGE IS THEN:

$$\frac{k_{02}}{k_{01}} \times 100$$

- * TESTS FOR EVALUATING PROSPECTIVE COMPLETION FLUIDS WITH RESPECT TO FORMATION DAMAGE SHOULD BE MADE ON FRESH PLUGS WITH THE INTERSTITIAL FLUIDS IN PLACE. DRYING AND EXTRACTING ALTERS THE WETTABILITY OF THE PORE SURFACES.

USEFUL PRELIMINARY TESTS ON CORES

1. EXTRACT THE CORE WITH AN AROMATIC SOLVENT: DRY, AND DETERMINE BOTH THE PERMEABILITY TO AIR AND THE POROSITY.
2. MAKE AN X-RAY ANALYSIS TO IDENTIFY CLAY MINERALS, OR, AT LEAST, MAKE A METHYLENE BLUE TEST TO EVALUATE CLAY MINERAL ACTIVITY.
3. ON CORES FROM VERY LOW PERMEABILITY RESERVOIRS, MAKE A MERCURY INJECTION TEST TO DETERMINE CAPILLARY PRESSURES.
4. ANALYZE A SAMPLE OF FORMATION WATER SOLUBLE SALTS.

TEST FOR DIAGNOSING CAUSES AND DEVISING REMEDIAL MEASURES

1. TO CHECK FOR THE EFFECT OF FILTRATE ON INDIGENOUS CLAYS WITHOUT INTERFERENCE BY PARTICLES FROM THE MUD, EXTRACT A LARGE VOLUME OF FILTRATE IN A MULTIPLE FILTER PRESS, AND REPEAT THE BRINE CORE TESTS. BUT, FLOOD WITH THE FILTRATE IN STEP 3 OF THE FLOW SEQUENCE (BRINE CORE TESTS). ADJUST THE PRESSURE DROP TO GIVE AN APPROPRIATE FLOW RATE, AND CONTINUE FLOW UNTIL CONSTANT PERMEABILITY IS OBTAINED.
2. CHECK THE WATER SATURATION AFTER THE INITIAL AND FINAL OIL FLOOD. IF THERE IS A LARGE DIFFERENCE, MAKE IMBIBITION TESTS TO DETERMINE IF THERE HAS BEEN A CHANGE IN WETTABILITY.
3. TO CHECK FOR IMPAIRMENT BY PARTICLES FROM THE MUD, EXTRACT AND DRY A PLUG, THEN FIRE AT 600° C FOR AT LEAST 6 HOURS TO INACTIVE INDIGENOUS CLAYS. REPEAT THE USUAL SEQUENCE OF FLOODS, USING THE TEST MUD IN STEP 3 OF THE FLOW SEQUENCE. ANY PERMEABILITY LOSS THEN REFLECTS THE DAMAGE CAUSED BY MUD PARTICLES ONLY. TO CHECK THE DEPTH OF INVASION, CUT OFF SUCCESSIVE SLICES OF THE PLUG, STARTING WITH 0.25 CM, AND PROCEED IN 1 CM STEPS, CHECKING THE PERMEABILITY OF THE REMAINDER OF THE PLUG UNTIL IT BECOMES CONSTANT. THIS TEST SHOULD BE USED IN DETERMINING THE OPTIMUM SIZE AND AMOUNT OF BRIDGING PARTICLES.
4. CHECK FOR MUTUAL PRECIPITATION BY MIXING MUD FILTRATE AND FORMATION WATER.

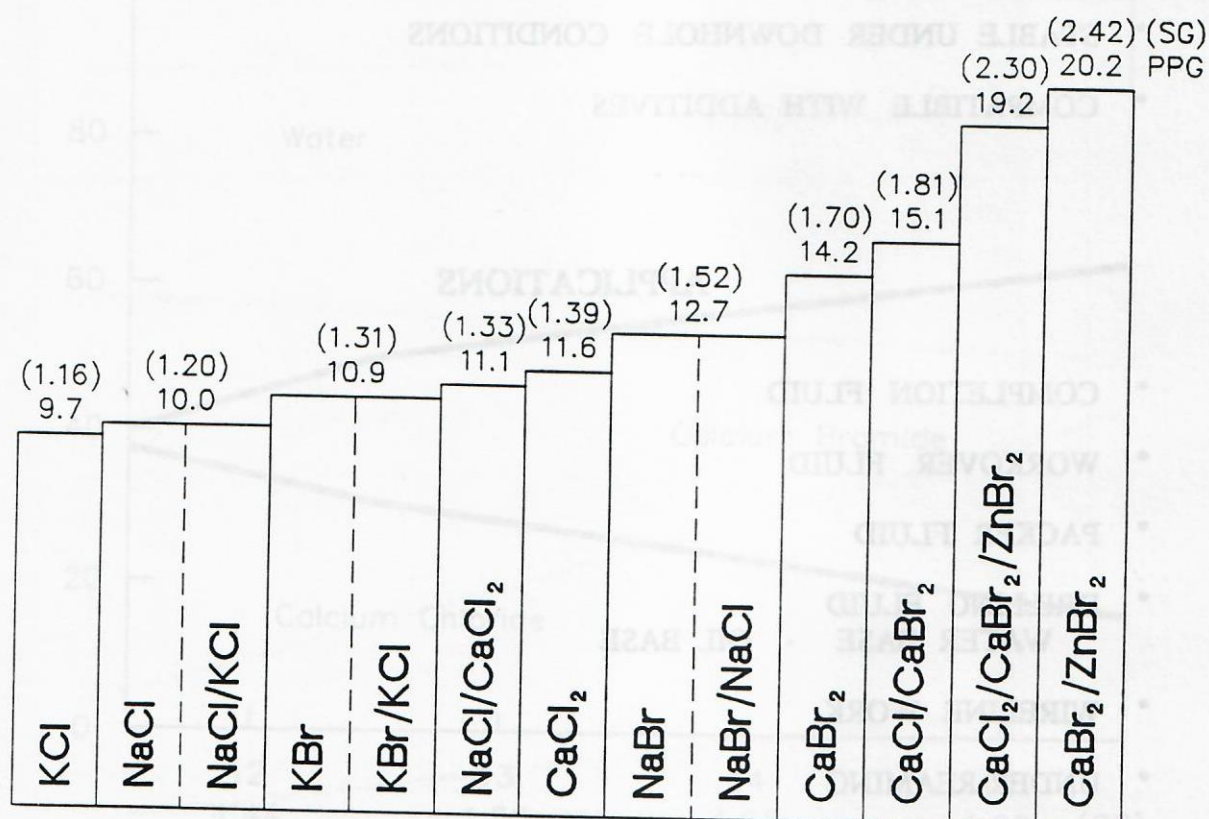
PROPER PROCEDURE FOR BRINGING A WELL ON PRODUCTION

1. ESTIMATE HOW DEEP THE DAMAGE TO FLUID PHASES
2. CALCULATE VOLUME OF PORE SPACES EFFECTED
3. MULTIPLY BY A SAFETY FACTOR AND FIELD EXPERIENCE
4. PRODUCE AT 1/2 ADJUSTED VOLUME FOR FIRST FEW DAYS
5. RAISE RATE IN SMALL INCREMENTS

CHARACTERISTICS OF COMMERCIALY AVAILABLE BRINES

SALTS	DENSITY RANGE lb/gal & SG				CRYSTALLIZATION TEMPERATURE RANGE, °F & °C			
	Min.	(SG)	Max.	(SG)	Min.	(°C)	Max.	(°C)
KCl	8.4	1.01	9.7	1.16	14	-10	60	16
NaCl	8.4	1.01	10.0	1.20	- 1	-18	31	-.56
NaBr	8.4	1.01	12.7	1.52	-28	-33	63	17
CaCl ₂	8.4	1.01	11.6	1.39	-59	-50	50	10
CaBr ₂	14.2	1.70	15.0	1.80	15	- 9	65	18
NaCl/CaCl ₂	10.1	1.21	11.1	1.33	-42	-41	0	-18
CaCl ₂ /CaBr ₂	11.1	1.33	15.1	1.81	-12	-24	68	20
CaBr ₂ /ZnBr ₂	14.3	1.71	19.2	2.30	-40	-40	23	- 5
CaCl ₂ /CaBr ₂ /ZnBr ₂	15.0	1.80	19.1	2.30	- 8	-22	64	18

DENSITY OF VARIOUS SALT SOLUTIONS USED FOR COMPLETION AND WORKOVER FLUIDS



DESIRED PROPERTIES OF COMPLETION FLUIDS

- ° NO PERMEABILITY DAMAGE
- ° CAPABLE OF BEING WEIGHTED TO DESIRED DENSITY
- ° ECONOMICAL AND AVAILABLE IN COMMERCIAL QUANTITIES
- ° SAFE FOR PEOPLE AND THE ENVIRONMENT
- ° LOW CORROSION RATES
- ° STABLE UNDER DOWNHOLE CONDITIONS
- ° COMPATIBLE WITH ADDITIVES

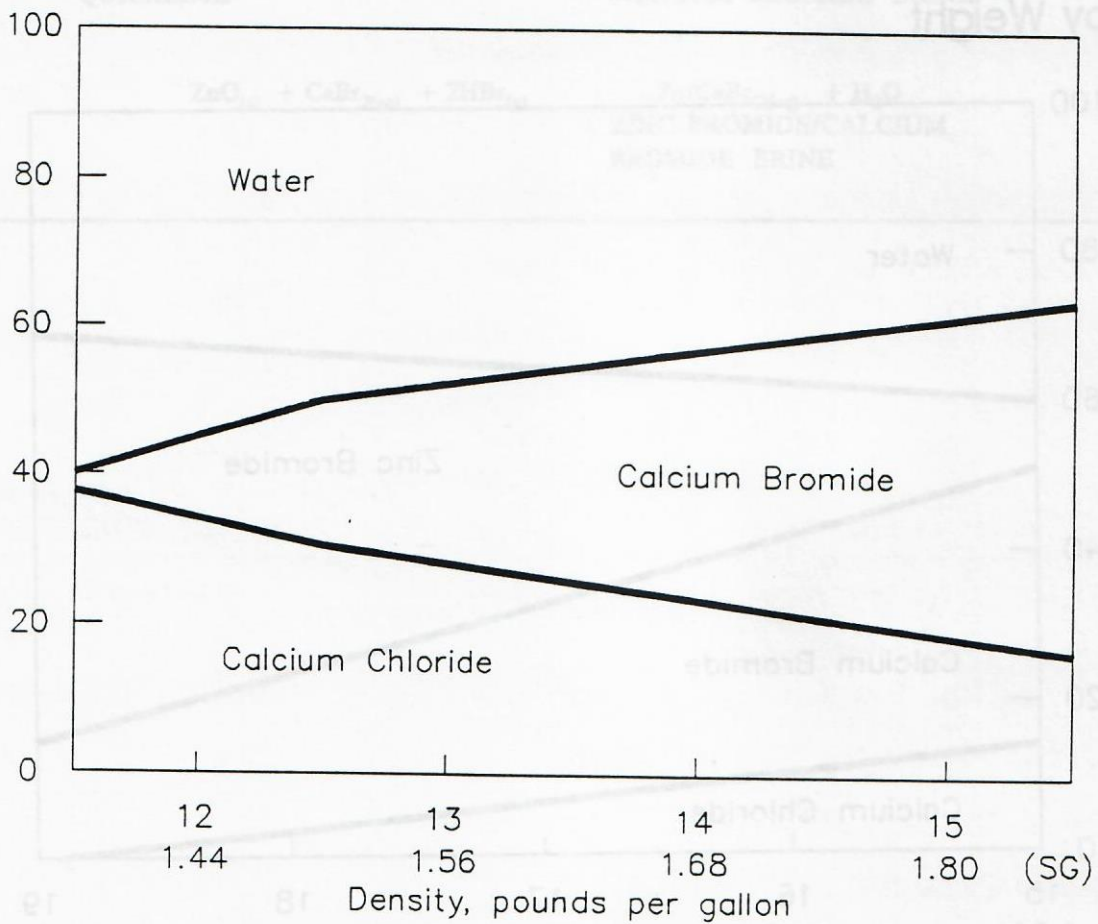
APPLICATIONS

- ° COMPLETION FLUID
- ° WORKOVER FLUID
- ° PACKER FLUID
- ° DRILLING FLUID
WATER BASE - OIL BASE
- ° WIRELINE WORK
- ° UNDER-REAMING
- ° GRAVEL PACKING
- ° SAND CONSOLIDATION
- ° PERFORATING

CHEMISTRY OF BROMIDE SALT SYNTHESIS

Density vs Concentration of a 2-Salt Brine

% by Weight

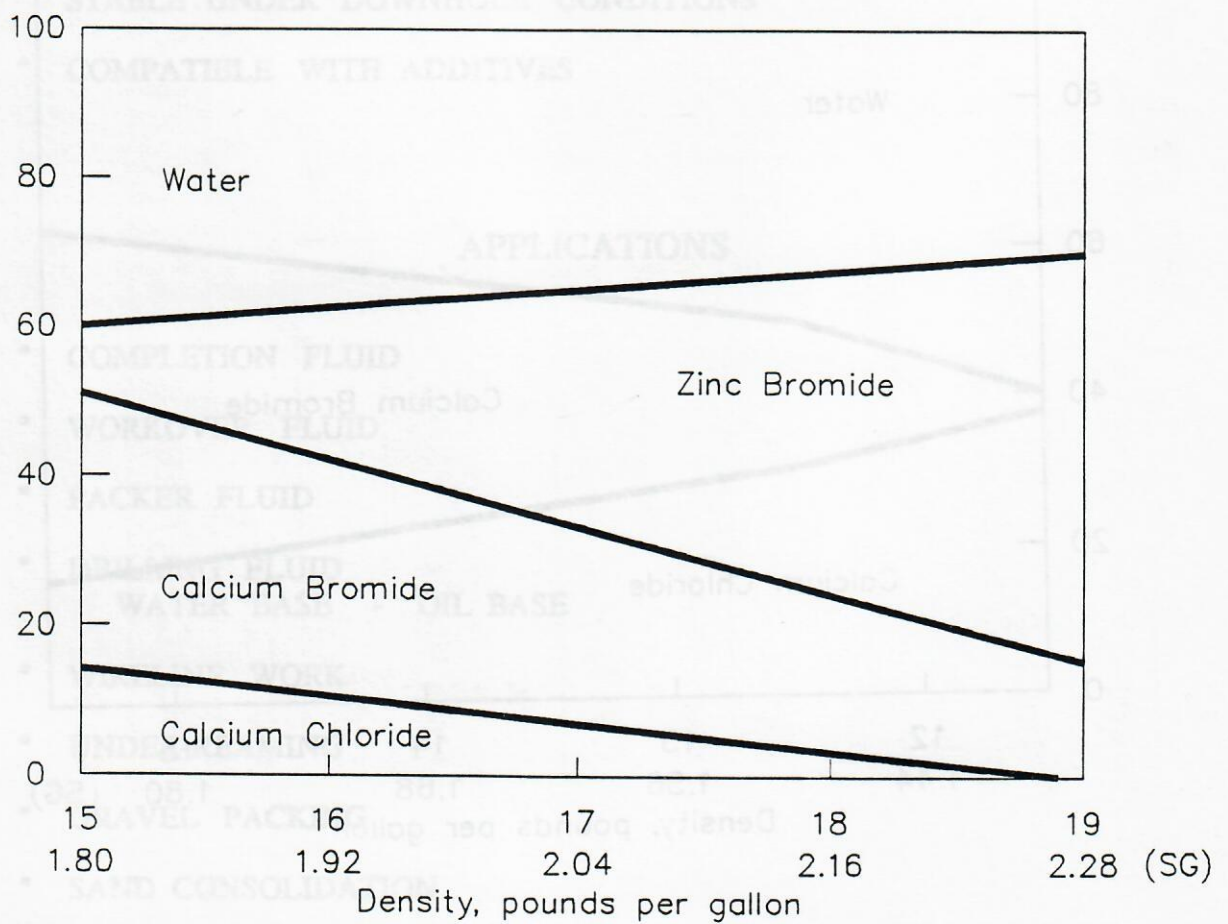


DESIRED PROPERTIES OF COMPLETION FLUIDS

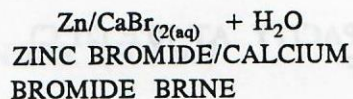
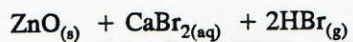
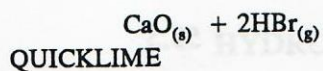
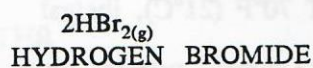
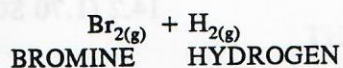
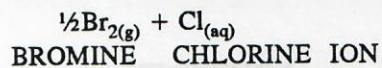
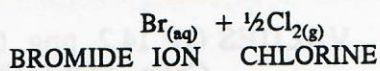
- NO PERMEABILITY DAMAGE
- CAPABLE OF BEING USED IN LARGE QUANTITIES
- ECONOMICAL AND AVAILABLE IN LARGE QUANTITIES
- SAFE FOR PEOPLE AND THE ENVIRONMENT

Density vs Concentration in 3-Salt Brine

% by Weight



CHEMISTRY OF BROMIDE SALT SYNTHESIS



TYPICAL PHYSICAL PROPERTIES

PROPERTY	VALUES OF 14.2 ppg (1.70 SG) CaBr ₂ SOLUTION
DENSITY AT 70°F (21°C), lbs/gal	14.2 (1.70 SG)
CRYSTALLIZATION POINT, TCP, (LCTD), °F & °C	8 (12) -13°C (-11°C)
CONCENTRATION, PERCENT SALT	53.5
pH MINIMUM, 1-10 DILUTION	7
HEAT CAPACITY AT 70°F (21°C), cal/g/°F	.47
VISCOSITY AT 70°F (21°C), cp	8
COEFFICIENT OF THERMAL EXPANSION AT 120°F (49°C) (bbl/bbl/°F $\times 10^{-4}$)	2.94

PROPERTY	VALUES OF 19.2 ppg (2.30 SG) ZnBr/CaBr SOLUTION
DENSITY AT 70°F (21°C), lbs/gal	19.2 (2.30 SG)
CRYSTALLIZATION POINT, TCP, (LCTD), °F & °C	14 (17) -10°C (-8°C)
CONCENTRATION, PERCENT SALT	75
pH MINIMUM, 1-10 DILUTION	4
HEAT CAPACITY AT 70°F (21°C), cal/g/°F	25
VISCOSITY AT 70°F (21°C), cp	27
COEFFICIENT OF THERMAL EXPANSION AT 120°F (49°C) (bbl/bbl/°F $\times 10^{-4}$)	4.61

BRINE TESTING EQUIPMENT

MUD BALANCE

THERMOMETER

HYDROMETERS (1.08 - 2.30 ASG)

THERMOMETER

GRADUATED CYLINDER (500 ml)

DEAERATOR

BRINE TEST KIT

CENTRIFUGE (HAND CRANK)

TURBIDITY METER (HACH)

TYPICAL PHYSICAL PROPERTIES

FACTORS TO CONSIDER

PROPERTY	DENSITY
DENSITY AT 70°F (21°C)	14.2 (1.70 SG)
CRYSTALLIZATION POINT (LCTD), °F & °C	1 (32) -15°C (-5°F)
CONCENTRATION, PERCENT SALT	1.5
PH MINIMUM, 1-10 DILUTION	7
HEAT CAPACITY AT 70°F (21°C)	1
VISCOSITY AT 70°F (21°C)	1
COEFFICIENT OF THERMAL EXPANSION AT 120°F (49°C)	1.5

DENSITY

FREEZE POINT

CORROSIVITY

HAZARDS TO:

PERSONNEL ENVIRONMENT

COMPATIBILITY WITH FORMATION

DEEP BED INVASION - ENTRAINED SOLIDS

WATER BLOCKS - EMULSIONS

LOGGING PROGRAM

Table 3.34

CALCIUM CHLORIDE / CALCIUM BROMIDE BRINE

Using 11.6 lb/gal CaCl_2 Brine
14.2 lb/gal CaBr_2 and Sacked CaCl_2

Brine Density at 60° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point, °F
	11.6 lb/gal CaCl_2 bbl	14.2 lb/gal CaBr_2 bbl	94-97% CaCl_2 lb	
11.7	.9714	.0254	3	+45
11.8	.9429	.0507	6	+51
11.9	.9143	.0762	9	+52
12.0	.8857	.1016	12	+54
12.1	.8572	.1269	15	+55
12.2	.8286	.1524	18	+55
12.3	.8000	.1778	21	+56
12.4	.7715	.2032	24	+56
12.5	.7429	.2286	27	+57
12.6	.7143	.2540	30	+57
12.7	.6857	.2794	33	+58
12.8	.6572	.3048	36	+58
12.9	.6286	.3302	39	+59
13.0	.6000	.3556	42	+59
13.1	.5714	.3810	45	+60
13.2	.5429	.4064	48	+60
13.3	.5143	.4318	52	+60
13.4	.4857	.4572	55	+61
13.5	.4572	.4826	58	+61
13.6	.4286	.5080	61	+62
13.7	.4000	.5334	64	+62
13.8	.3714	.5589	67	+63
13.9	.3429	.5842	70	+63
14.0	.3143	.6069	73	+64

Table 3.34

CALCIUM CHLORIDE / CALCIUM BROMIDE BRINE

Using 11.6 lb/gal CaCl_2 Brine
 14.2 lb/gal CaBr_2 and Sacked CaCl_2
 (Continued)

Brine Density at 60° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point, °F
	11.6 lb/gal CaCl_2 bbl	14.2 lb/gal CaBr_2 bbl	94-97% CaCl_2 lb	
14.1	.2857	.6351	76	+64
14.2	.2572	.6604	79	+64
14.3	.2286	.6858	82	+65
14.4	.2000	.7113	85	+65
14.5	.1715	.7366	89	+65
14.6	.1429	.7620	91	+66
14.7	.1143	.7875	94	+66
14.8	.0858	.8128	97	+67
14.9	.0572	.8382	100	+67
15.0	.0286	.8637	103	+67
15.1	.0000	.8891	106	+68

* Flakes or pellets

CALCIUM CHLORIDE / CALCIUM BROMIDE BRINE

Using 10.9 lb/gal CaCl_2 Brine and
14.2 lb/gal CaBr_2 Brine

Brine Density at 60° F lb/gal	10.9 lb/gal CaCl_2 bbl	14.2 lb/gal CaBr_2 bbl	Crystallization Point, °F
10.9	1.000	0.000	-30
11.0	0.970	0.030	-18
11.1	0.939	0.061	-12
11.2	0.909	0.091	-11
11.3	0.879	0.121	-11
11.4	0.849	0.151	-11
11.5	0.818	0.182	-11
11.6	0.788	0.212	-11
11.7	0.758	0.242	-12
11.8	0.727	0.273	-12
11.9	0.697	0.303	-12
12.0	0.666	0.333	-12
12.1	0.636	0.364	-12
12.2	0.606	0.394	-12
12.3	0.576	0.424	-12
12.4	0.546	0.454	-13
12.5	0.515	0.485	-13
12.6	0.485	0.515	-14
12.7	0.455	0.545	-15
12.8	0.424	0.576	-16
12.9	0.394	0.606	-17
13.0	0.364	0.636	-18
13.1	0.333	0.667	-19
13.2	0.303	0.697	-22
13.3	0.273	0.727	-20
13.4	0.243	0.757	-19
13.5	0.212	0.788	-18

COMPOSITION OF ONE BARREL OF CALCIUM CHLORIDE / CALCIUM BROMIDE

Using Sacked Salts

Brine Density* lb/gal	To make 1 bbl (42 gal)		
	Water	95% CaCl ₂	95% CaBr ₂
11.7	0.832	192.3	8.1
11.8	0.828	189.8	16.2
11.9	0.822	187.3	24.5
12.0	0.819	184.7	32.7
12.1	0.815	182.2	40.7
12.2	0.811	179.7	48.9
12.3	0.807	177.1	57.1
12.4	0.803	174.6	65.3
12.5	0.798	172.1	73.3
12.6	0.794	169.5	81.5
12.7	0.790	167.0	89.7
12.8	0.786	164.4	97.8
12.9	0.782	161.9	106.1
13.0	0.778	159.4	114.3
13.1	0.773	156.8	122.4
13.2	0.769	154.3	130.5
13.3	0.762	149.2	146.8
13.5	0.758	146.7	154.9
13.6	0.754	144.1	163.1
13.7	0.750	141.6	171.3
13.8	0.746	139.1	179.4
13.9	0.742	136.5	187.6
14.0	0.738	134.0	195.8
14.1	0.734	131.5	203.3
14.2	0.730	128.9	212.0
14.3	0.726	126.4	220.2
14.4	0.721	123.8	228.3

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE BRINE

Using 15.0 lb/gal $\text{CaCl}_2/\text{CaBr}_2$ Brine and
19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$

To make 1 bbl (42 gal)			
Brine Density at 60° F lb/gal	15.0 lb/gal $\text{CaCl}_2/\text{CaBr}_2$ bbl	19.2 lb/gal $\text{CaBr}_2/\text{ZnBr}_2$ bbl	Crystallization Point °F
15.0	1.000	.000	+64
15.1	.976	.024	62
15.2	.952	.048	61
15.3	.929	.071	59
15.4	.905	.095	59
15.5	.881	.119	59
15.6	.857	.143	58
15.7	.833	.167	57
15.8	.810	.190	55
15.9	.786	.214	54
16.0	.762	.238	53
16.1	.738	.262	52
16.2	.714	.286	50
16.3	.690	.310	50
16.4	.667	.333	49
16.5	.643	.357	47
16.6	.619	.381	46
16.7	.592	.405	43
16.8	.571	.429	40
16.9	.548	.452	36
17.0	.524	.476	32
17.1	.500	.500	28
17.2	.476	.524	31
17.3	.452	.548	35
17.4	.429	.571	37
17.5	.405	.592	41
17.6	.381	.619	45

CALCIUM BROMIDE / ZINC BROMIDE BRINE

Using 14.2 lb/gal CaBr_2 Brine and
19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$

Brine Density at 60° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point °F
	14.2 lb/gal CaBr_2 bbl	19.2 lb/gal $\text{CaBr}_2/\text{ZnBr}_2$ bbl	
15.0	.840	.160	-22
15.1	.820	.180	-25
15.2	.800	.200	-27
15.3	.780	.220	-29
15.4	.760	.240	-32
15.5	.740	.260	-34
15.6	.720	.280	-35
15.7	.700	.300	-38
15.8	.680	.320	-40
15.9	.660	.340	-37
16.0	.640	.360	-33
16.1	.620	.380	-30
16.2	.600	.400	-26
16.3	.580	.420	-23
16.4	.560	.440	-20
16.5	.540	.460	-16
16.6	.520	.480	-11
16.7	.500	.500	- 8
16.8	.480	.520	- 6
16.9	.460	.540	- 4
17.0	.440	.560	- 4
17.1	.420	.580	- 2
17.2	.400	.600	0
17.3	.380	.620	+ 2
17.4	.360	.640	+ 4
17.5	.340	.660	+ 5
17.6	.320	.680	+ 5

EXAMPLE OF MIXING CALCULATIONS

ALTERNATIVE A

0.744 BBL (.188 m³) WATER

336 POUNDS CaBr₂

0.720 BBL (.114 m³) 14.2 PPG (1.7 SG) CaBr₂

0.280 BBL (.044 m³) 19.2 PPG (2.3 SG) ZnBr₂

15.6 PPG (1.87 SG) BRINE

-35°F (-37°C) CRYSTALLIZATION POINT

\$616.00 PER BBL

51% DIFFERENCE IN PRICE

ALTERNATIVE B

0.8637 BBL (.137 m³) 14.2 PPG (1.7 SG) CaBr₂

108.67 POUNDS CaCl₂

0.024 BBL (.004 m³) H₂O

0.857 BBL (.136 m³) 15.0 PPG (1.8 SG) CaBr₂

0.143 BBL (.023 m³) 19.2 PPG (2.30 SG) ZnBr₂

15.6 PPG (1.87 SG) BRINE

58°F (14°C) CRYSTALLIZATION POINT

\$304.90 PER BBL

CALCIUM BROMIDE / ZINC BROMIDE BRINE

PROCESS INVOLVED IN CRYSTALLIZATION

Using 14.2 lb/gal CaBr₂ Brine and
19.2 lb/gal ZnBr₂/CaBr₂

VARIABLES

SALT TYPE

SALT CONTENT

COOLING RATE

DEGREE OF AGITATION

MECHANISMS INVOLVED IN CRYSTALLIZATION

SUPER COOLING

NUCLEATION

THERMAL FLUX

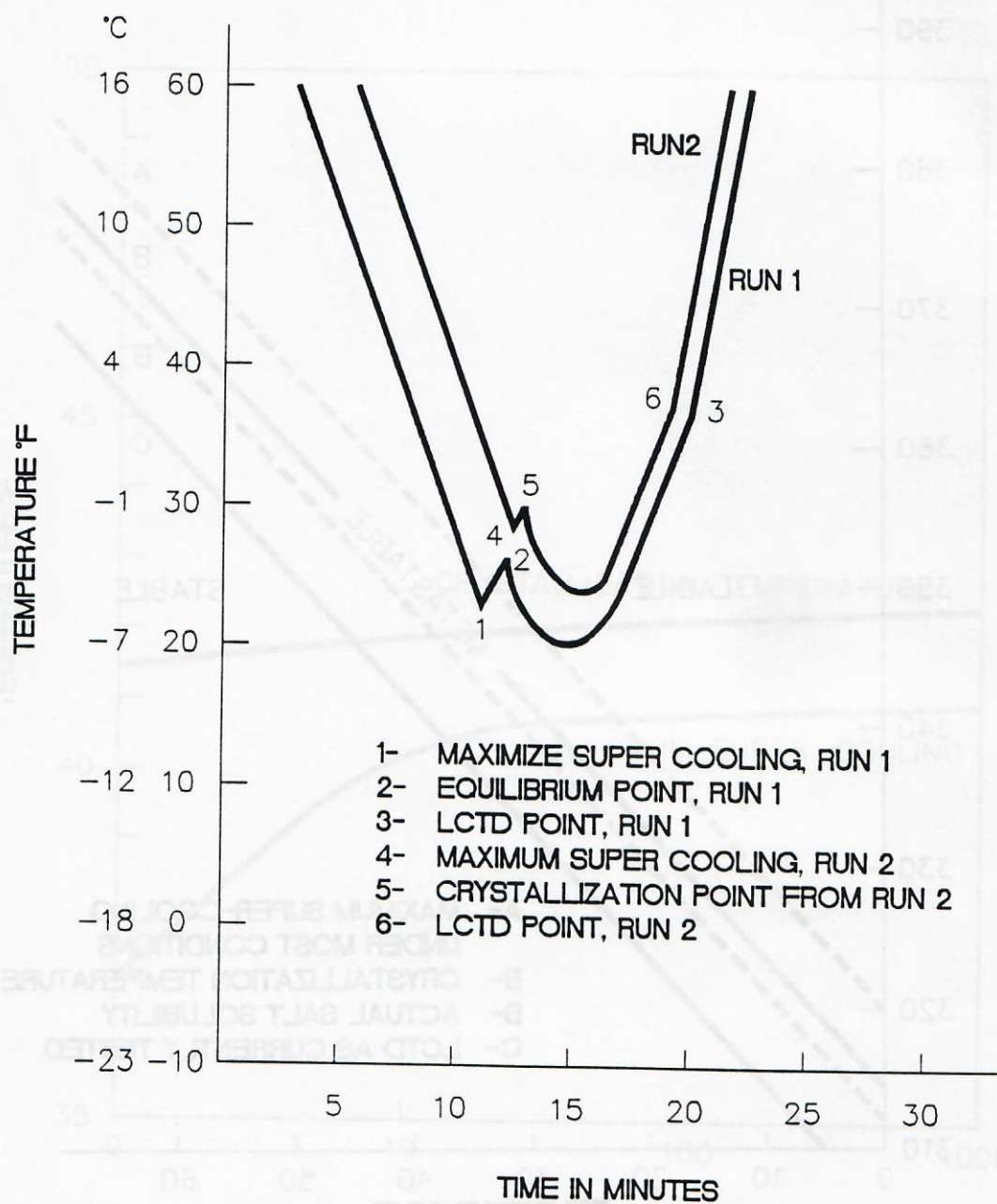
MECHANICAL AGITATION

IMPURITIES

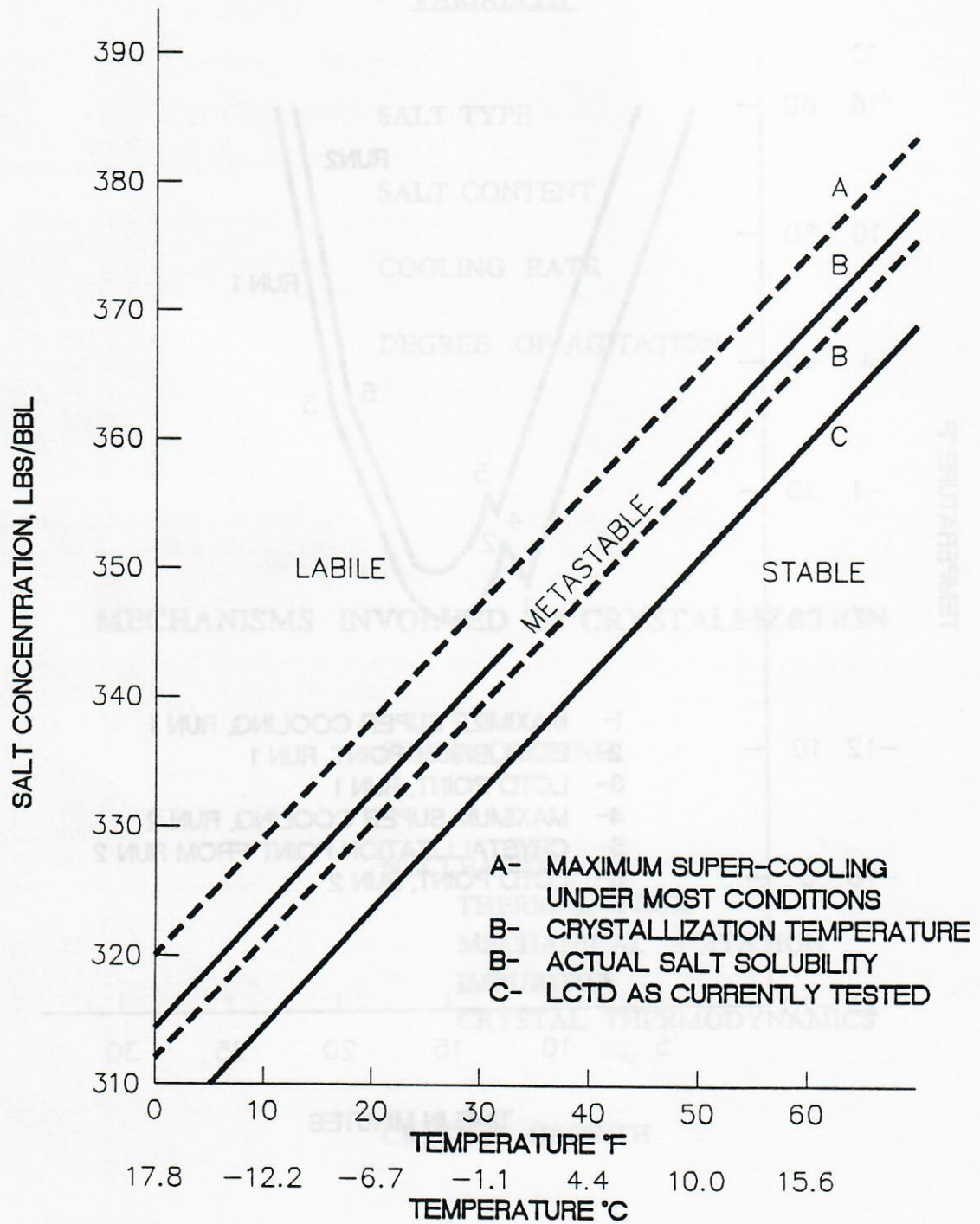
CRYSTAL THERMODYNAMICS

CRYSTAL GROWTH

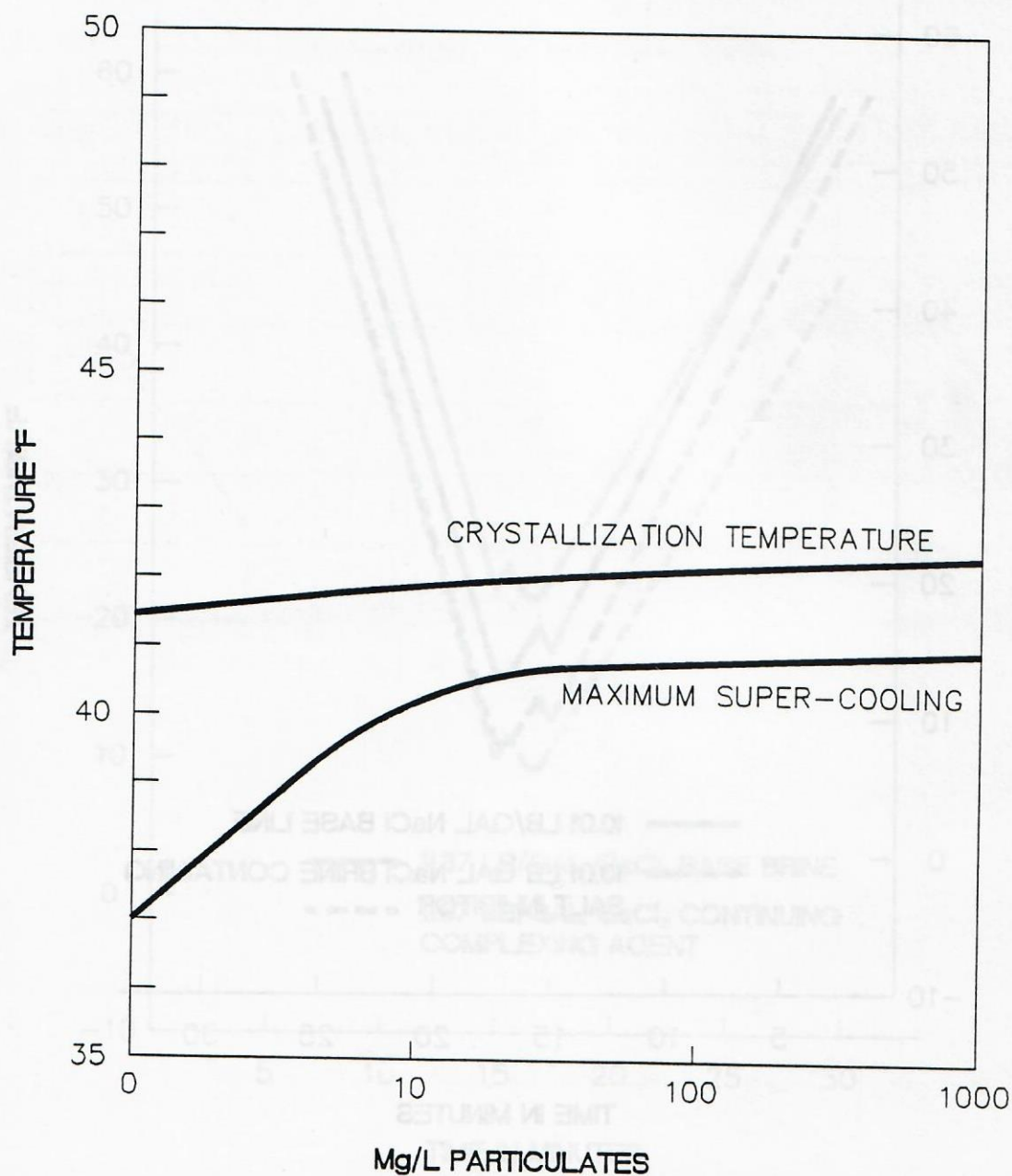
DUAL RUNS MINIMIZE SUPER-COOLING WHEN TESTING FOR CRYSTALLIZATION POINT



CALCIUM BROMIDE SOLUBILITY, 0°-70° F

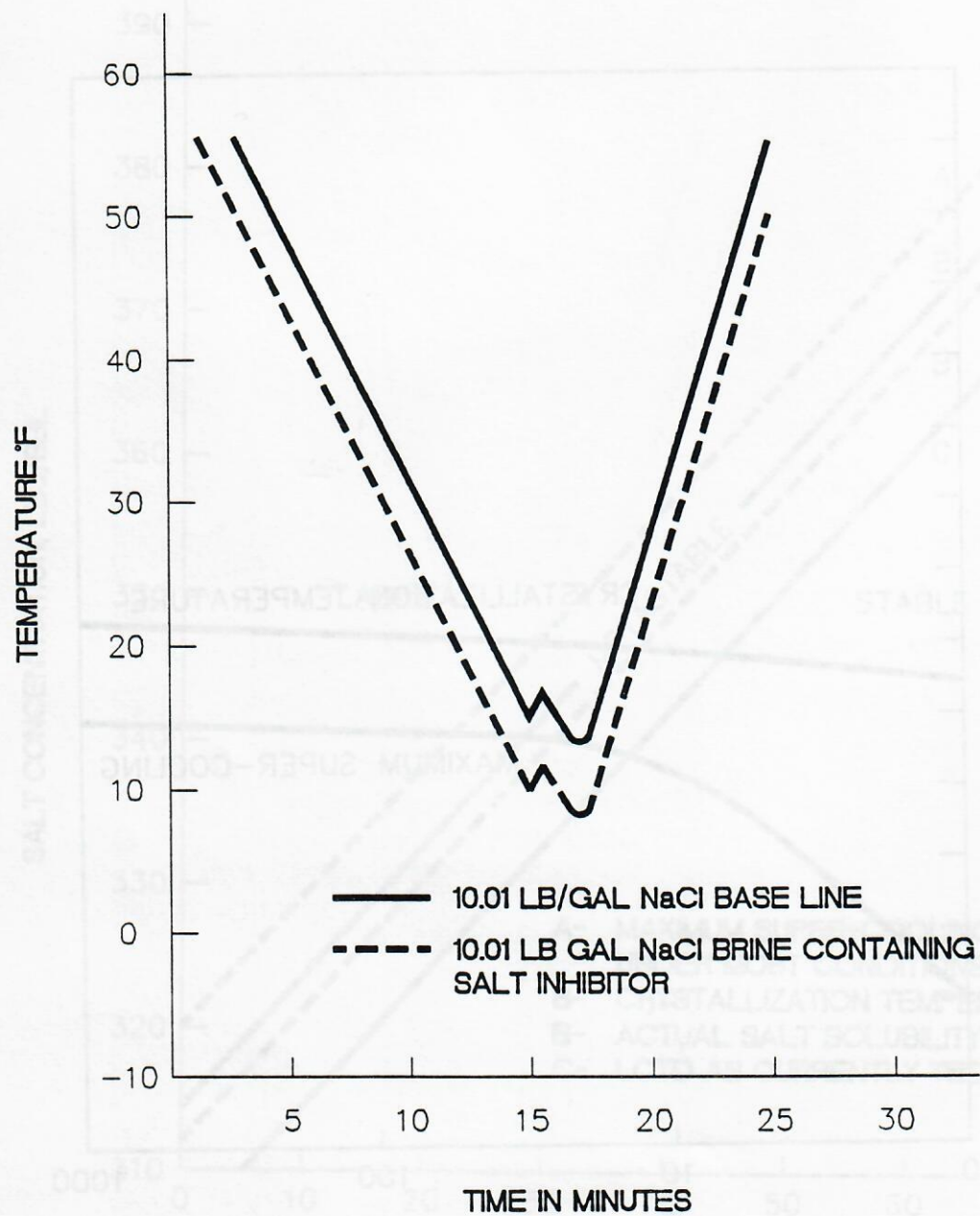


EFFECT OF SOLID PARTICULATES ON CRYSTALLIZATION POINT MEASUREMENT, 14.7 LB/GAL CaBr_2 BRINE

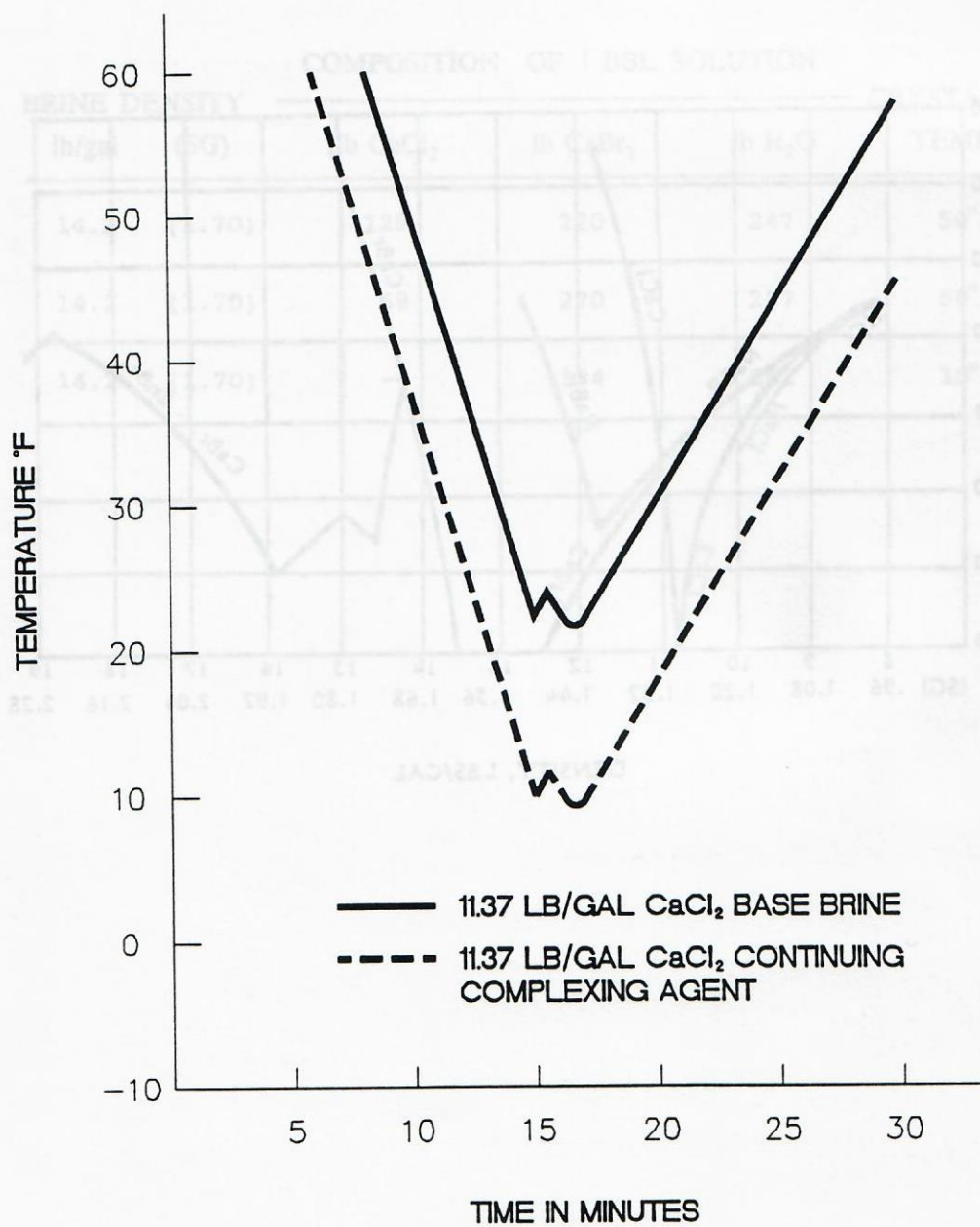


8067 46171-861
063 585 92 91

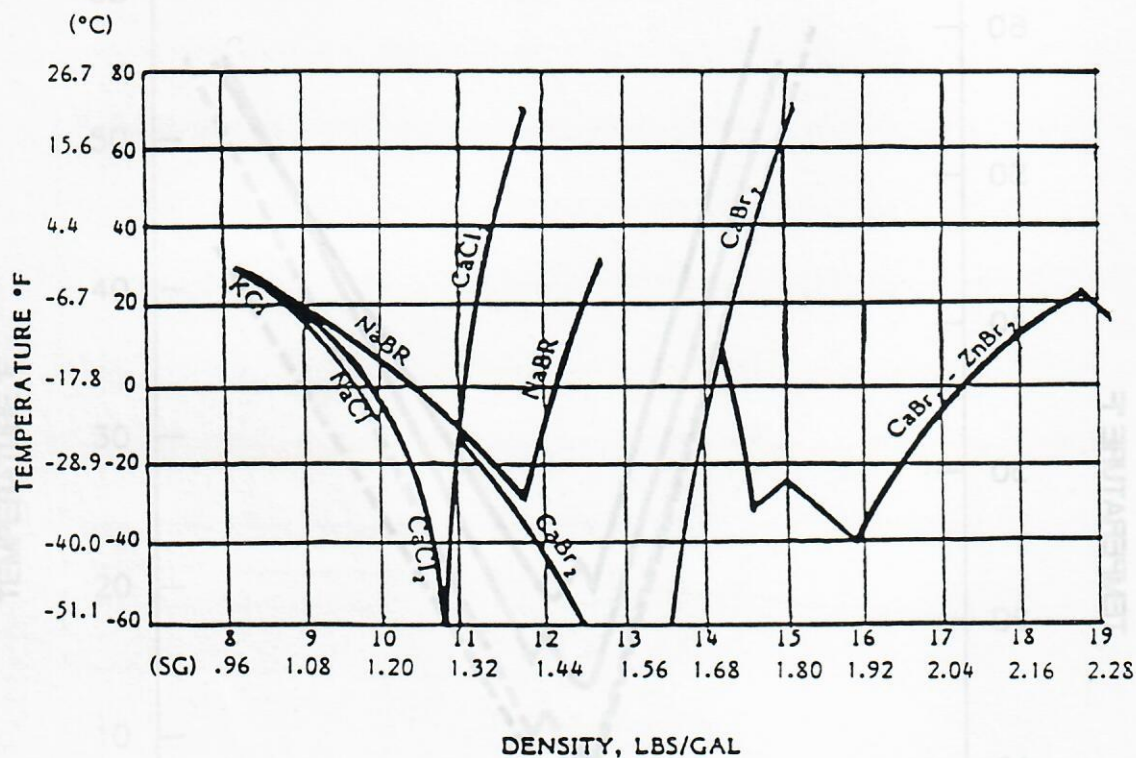
COOLING CURVE TEST - EFFECT OF SALT INHIBITOR



COOLING CURVE TEST - EFFECT OF COMPLEXING AGENT



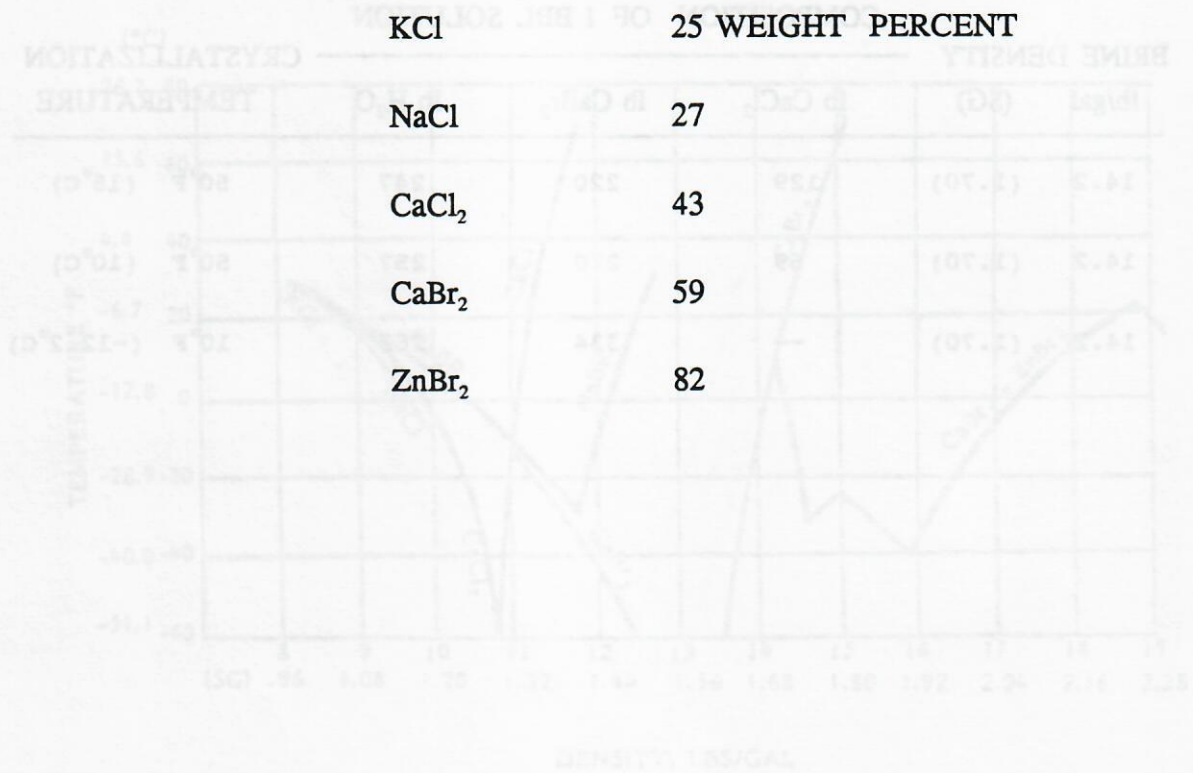
CRYSTALLIZATION TEMPERATURES FOR SALT SOLUTIONS

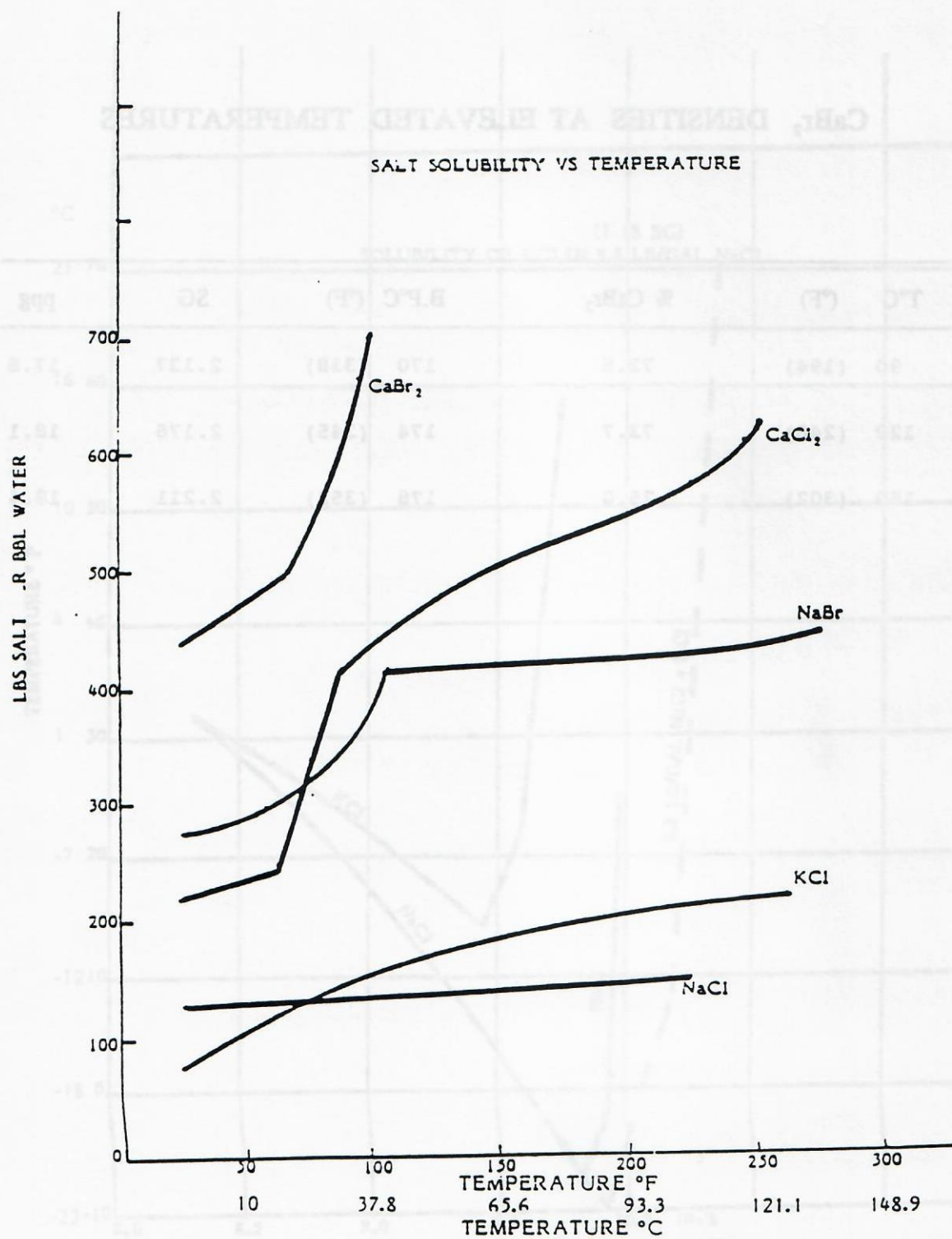


EFFECT OF COMPOSITION ON CRYSTALLIZATION TEMPERATURE

BRINE DENSITY		COMPOSITION OF 1 BBL SOLUTION			CRYSTALLIZATION TEMPERATURE
		lb CaCl ₂	lb CaBr ₂	lb H ₂ O	
14.2	(1.70)	129	220	247	50°F (15°C)
14.2	(1.70)	69	270	257	50°F (10°C)
14.2	(1.70)	--	334	262	10°F (-12.2°C)

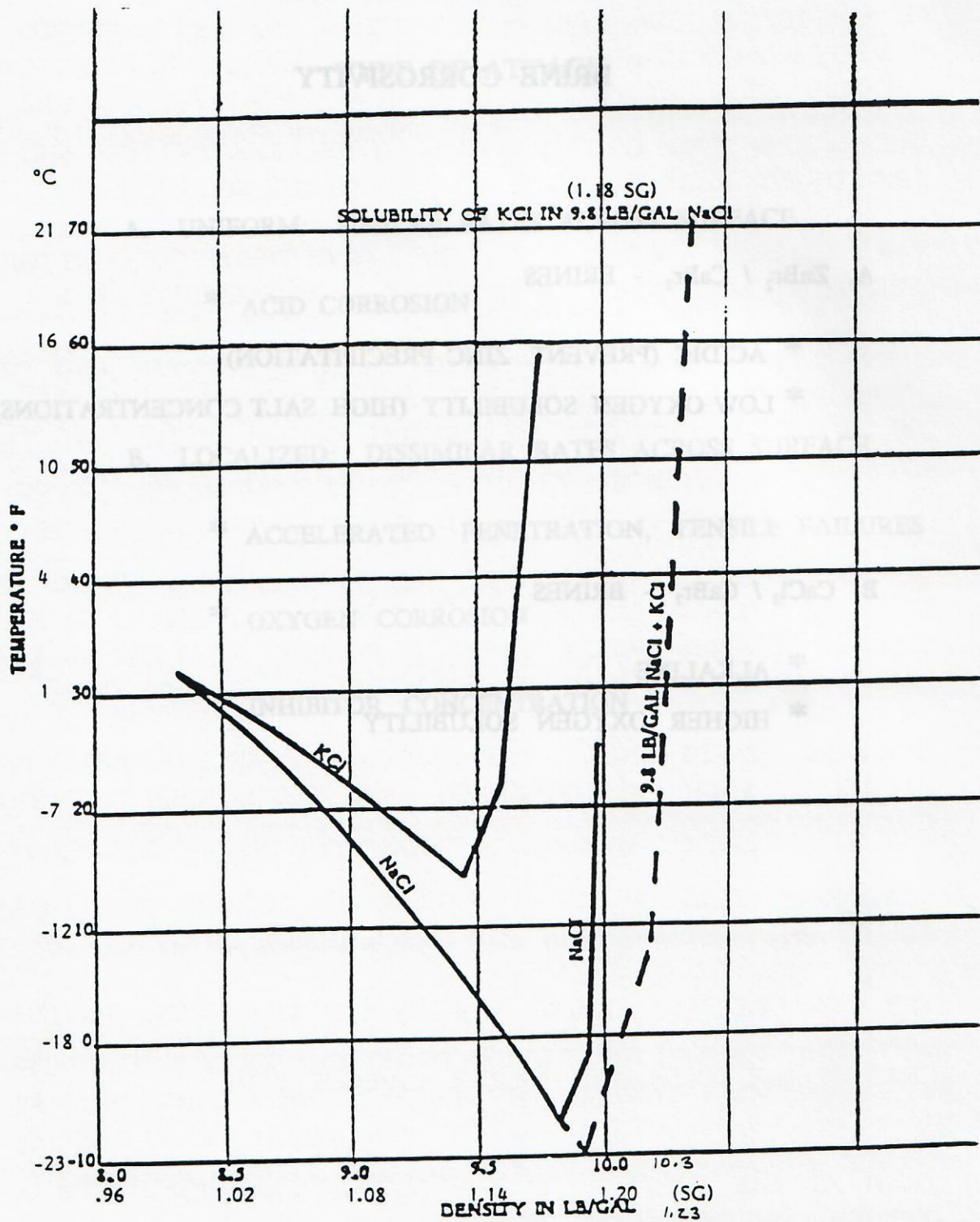
SOLUBILITY OF SALTS IN WATER (68°F)





CaBr₂ DENSITIES AT ELEVATED TEMPERATURES

T°C	(°F)	% CaBr ₂	B.P°C (°F)	SG	ppg
90	(194)	72.5	170 (338)	2.137	17.8
120	(248)	73.7	174 (345)	2.176	18.1
150	(302)	75.0	178 (352)	2.211	18.4



BRINE CORROSIVITY

A. ZnBr_2 / CaBr_2 - BRINES

- * ACIDIC (PREVENT ZINC PRECIPITATION)
- * LOW OXYGEN SOLUBILITY (HIGH SALT CONCENTRATIONS)

B. CaCl_2 / CaBr_2 - BRINES

- * ALKALINE
- * HIGHER OXYGEN SOLUBILITY

TYPE OF ATTACK

A. UNIFORM: SIMILAR RATES ACROSS SURFACE

* ACID CORROSION

B. LOCALIZED: DISSIMILAR RATES ACROSS SURFACE

* ACCELERATED PENETRATION, TENSILE FAILURES

* OXYGEN CORROSION

* INHIBITOR CONCENTRATION

CORROSION PROCESS

IF A METAL IS PLACED IN A SOLUTION OF ONE OF ITS SALTS, THE METAL IONS TEND TO PASS INTO SOLUTION, LEAVING THE METAL NEGATIVELY CHARGED WITH RESPECT TO THE SOLUTION.

ONLY A MINUTE AMOUNT OF CATIONS LEAVE THE METAL, AND THEY ARE HELD CLOSE TO THE SURFACE BY ITS NEGATIVE CHARGE.

AN ELECTROSTATIC DOUBLE LAYER IS THUS FORMED, AND THE NEGATIVE CHARGE IS THE NERNST SURFACE POTENTIAL, THE VALUE OF WHICH IS A FUNCTION OF IDENTITY OF THE METAL AND THE CONCENTRATION - OR RATHER THE ACTIVITY - OF THE SALT SOLUTION.

ELECTROCHEMICAL ACTIVITY IS THE FUNDAMENTAL CAUSE OF CORROSION. LOCAL DIFFERENCES IN SURFACE POTENTIAL CAUSED BY LACK OF HOMOGENEITY OF METAL PROVIDE SITES FOR ANODES AND CATHODES. THE BODY OF THE METAL IS THE CONDUCTOR.

CORROSION TAKES PLACE AT THE ANODE AND CORROSION REACTION PRODUCTS, SUCH AS HYDROGEN, ARE DISCHARGED AT THE CATHODE.

CORROSION CELLS ARE SET UP IN DRILL PIPE BECAUSE STEEL IS AN ALLOY, AND CONTAINS IRON AND IRON CARBIDE CRYSTALS.

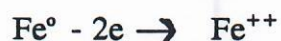
THE IRON CRYSTALS ALMOST ALWAYS ACT AS ANODES, THE IRON CARBIDE CRYSTALS ALMOST ALWAYS ACT AS CATHODES. THE CIRCUITS ARE COMPLETED BY THE AQUEOUS FLUID.

OXYGEN CORROSION CELL - LESS OXYGEN UNDER SCALE (ANODE) THAN AT THE SURFACE OF THE METAL (CATHODE), THUS AN OXYGEN CONCENTRATION CELL.

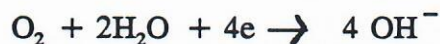
ANOTHER TYPE OF ELECTROCHEMICAL CELL IS SET UP BY DIFFERENCES IN OXIDIZING CONDITIONS, FUNDAMENTALLY BECAUSE OXIDATION INVOLVES A GAIN OF ELECTRONS, E.G., WHEN FERROUS IRON IS CONVERTED TO FERRIC IRON:



POTENTIAL DIFFERENCES CAUSED BY THIS MECHANISM ARE CALLED REDOX POTENTIALS. IN A DRILLING WELL, OXYGEN IS INEVITABLY ENTRAINED IN THE MUD AT THE SURFACE BY MIXING AND CONDITIONING OPERATIONS. DOWNHOLE, THE SURFACE OF THE PIPE IS EXPOSED TO OXIDIZING CONDITIONS, BUT REDUCING CONDITIONS PREVAIL UNDER PATCHES OF RUST OR OTHER BARRIERS. AN ANODE IS THEREFORE SET UP UNDER THE BARRIER AS FOLLOWS:



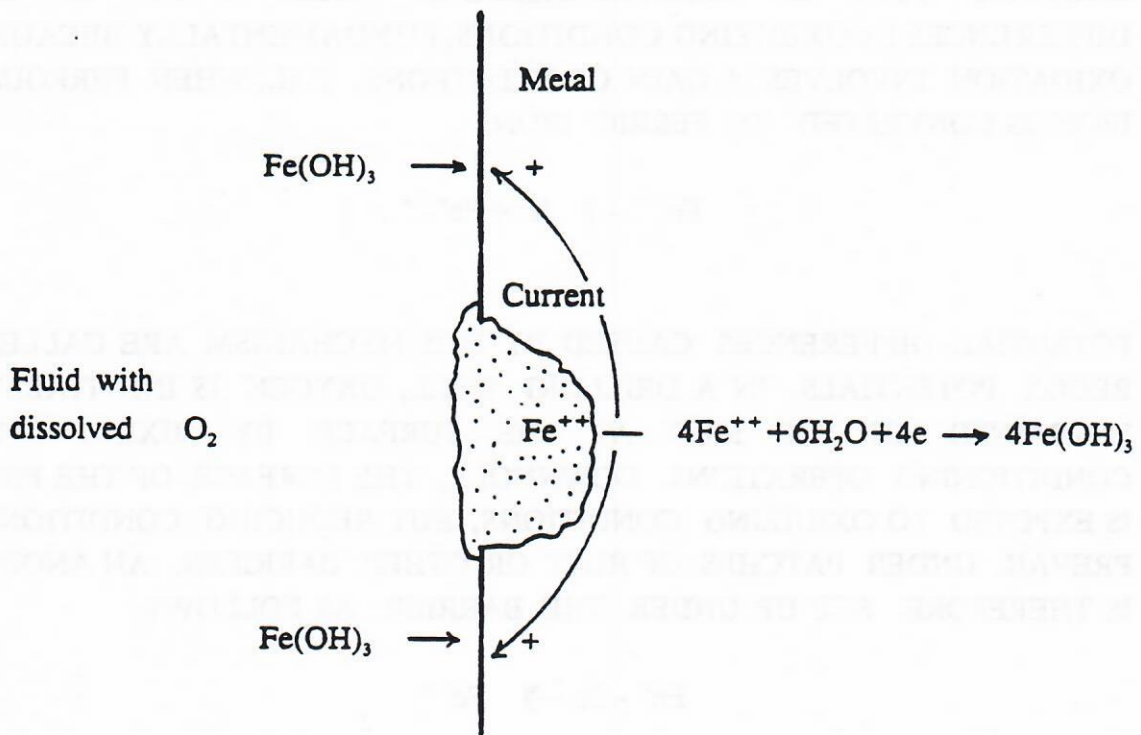
AND A CATHODE AT THE SURFACE OF THE PIPE:



DEPOSITING FERRIC HYDROXIDE ACCORDING TO THE EQUATION:



CORROSION PITS ARE THUS FORMED UNDER SCALE. CORROSION WILL STILL OCCUR EVEN THOUGH THERE IS SOME OXYGEN UNDER THE BARRIER. THE ESSENTIAL CONDITION IS THAT LESS OXYGEN BE PRESENT UNDER THE BARRIER THAN AT THE BARE SURFACE OF THE METAL, THUS ESTABLISHING AN OXYGEN CONCENTRATION CELL.



OXYGEN CORROSION CELL

IF THE PRODUCTS OF CORROSION ACCUMULATE AT THE CATHODE, THE FLOW OF ELECTRONS IS IMPEDED, AND THE CORROSION PROCESS SLOWS UP. THE CATHODE IS THEN SAID TO BE POLARIZED.

EXAMPLE OF POLARIZING

CATIONS OF HYDROGEN MAY POLARIZE A CATHODE BY COATING IT WITH A LAYER OF HYDROGEN ATOMS. IF HYDROGEN ATOMS UNITE AND BUBBLE OFF AS MOLECULAR HYDROGEN, THE CATHODE IS SAID TO BE POLARIZED. DISSOLVED OXYGEN CAN ACT AS A DEPOLARIZER BY REACTING WITH THE HYDROGEN TO FORM H_2O THUS ACCELERATING THE CORROSION PROCESS.

THE CARBONIC ACID CAUSES A REDUCTION IN pH OF THE WATER WHICH MAKES IT QUITE CORROSIVE TO STEEL.

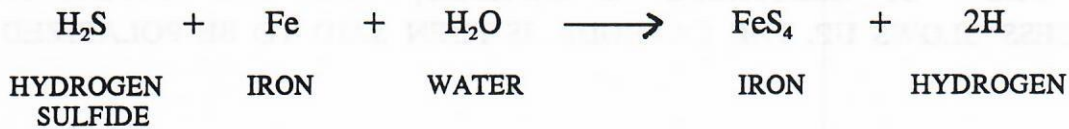


OXYGEN CORROSION



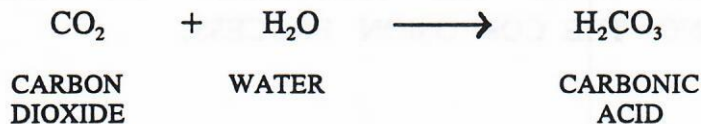
THIS EQUATION SHOWS THAT IRON COMBINES WITH OXYGEN AND WATER TO FORM RUST. THIS TYPE OF CORROSION CAN BE IDENTIFIED BY THE $Fe(OH)_3$ (YELLOW) AND Fe_2O_3 (ORANGE) CORROSION PRODUCTS WHICH ARE SEEN ON STEEL.

HYDROGEN SULFIDE CORROSION



GENERAL MECHANISM - NOT COMPLETELY STATED CHEMICALLY.

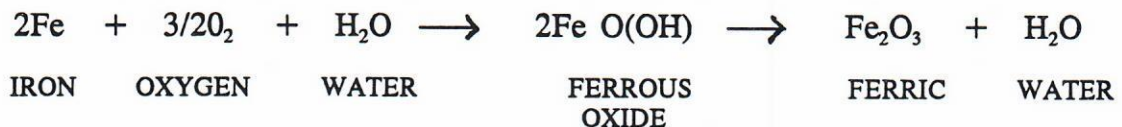
CARBON DIOXIDE CORROSION



THE CARBONIC ACID CAUSES A REDUCTION IN pH OF THE WATER WHICH MAKES IT QUITE CORROSIVE TO STEEL.



OXYGEN CORROSION



THIS EQUATION SHOWS THAT IRON COMBINES WITH OXYGEN AND WATER TO FORM RUST. THIS TYPE OF CORROSION CAN BE IDENTIFIED BY THE FeO(OH) (YELLOW) AND Fe₂O₃ (ORANGE) CORROSION PRODUCTS WHICH ARE SEEN ON STEEL.

OXYGEN CORROSION

**ONLY A FEW PARTS PER MILLION ARE SUFFICIENT FOR
SIGNIFICANT CORROSION**

OXYGEN CORROSION CELLS UNDER PATCHES OF RUST OR SCALE

INCREASE IN TEMPERATURE INCREASES CORROSION RATE

**INCREASE IN SALINITY INCREASES CORROSION RATE.
(FLUID IS MORE CONDUCTIVE)**

AT HIGH SALINITIES LESS OXYGEN IS PRESENT

CORROSION CONTROL IN BRINE FLUIDS

KEEP PIPE CLEAN

**TREAT WITH OXYGEN SCAVENGER IN LIGHT WEIGHT SYSTEMS
WHEN CIRCULATING**

USE FILMING INHIBITOR ON PIPE DURING TRIPS

USE CORROSION INHIBITOR DURING WORKOVER OPERATION

INHIBITOR ARE REMOVED FROM FLUID DURING FILTRATION

**ADD INHIBITOR ON LAST CIRCULATION WHEN LEAVING BRINE AS
A PACKER FLUID**

DO NOT TRY TO ADJUST THE pH OF BRINES

**ADD ONLY AMOUNT ON INHIBITOR RECOMMENDED BY
MANUFACTURER. EXCESSIVE AMOUNTS OF INHIBITOR CAN
ACCELERATE CORROSION**

CORROSION PROTECTION

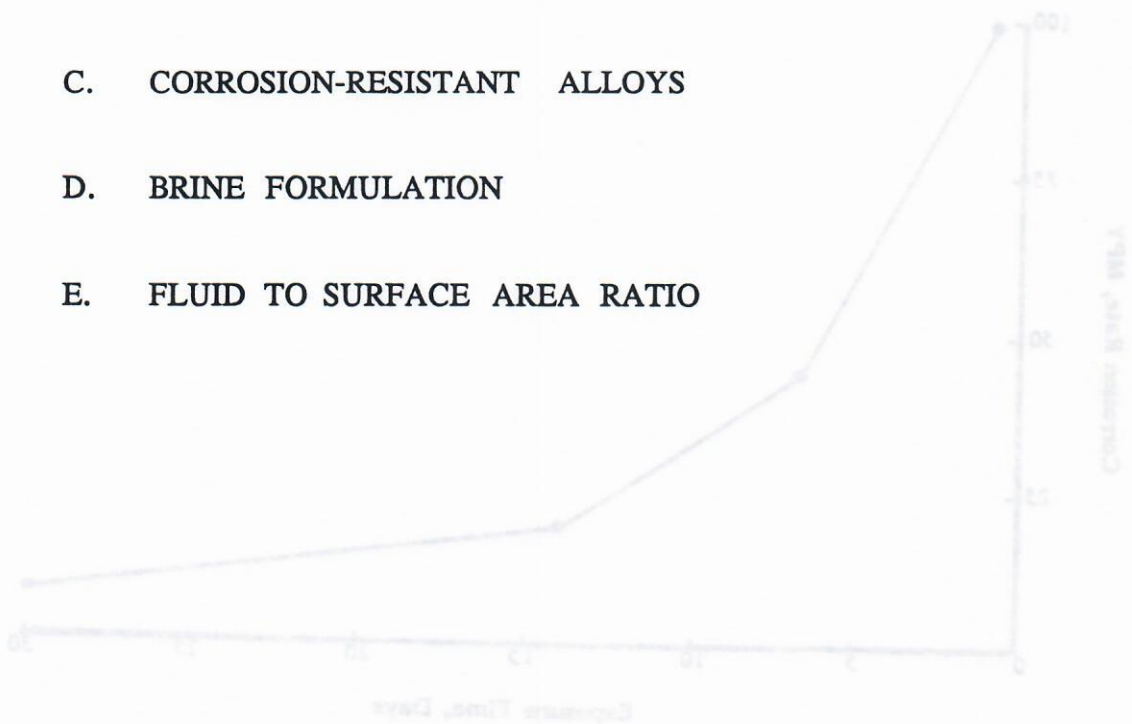
A. INHIBITORS: FORM PROTECTIVE FILMS ON STEEL SURFACES

B. SCAVENGERS: REACT WITH CORRODENT BEFORE CORRODENT OXIDIZES IRON

C. CORROSION-RESISTANT ALLOYS

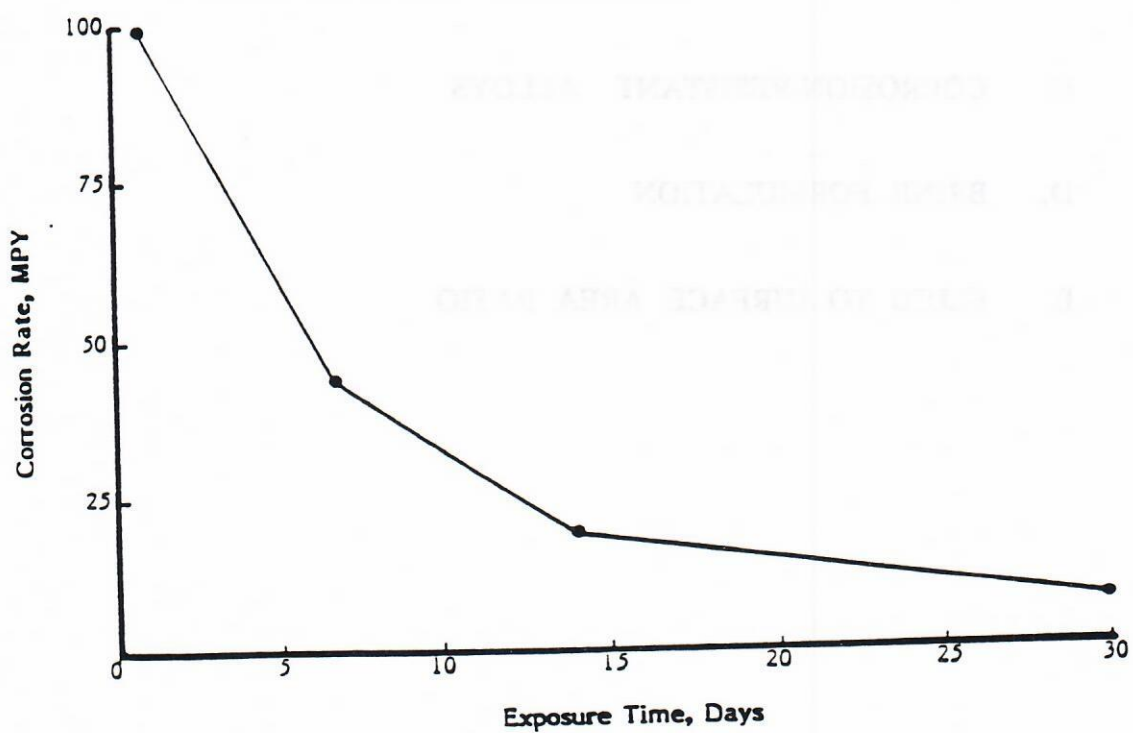
D. BRINE FORMULATION

E. FLUID TO SURFACE AREA RATIO



Corrosion Rate of Uninhibited 15.0 ppg $\text{CaCl}_2/\text{ZnBr}_2$ at 400°F, 1000 psi on N80 Steel

Corrosion Rate is Dependent on Length of Test

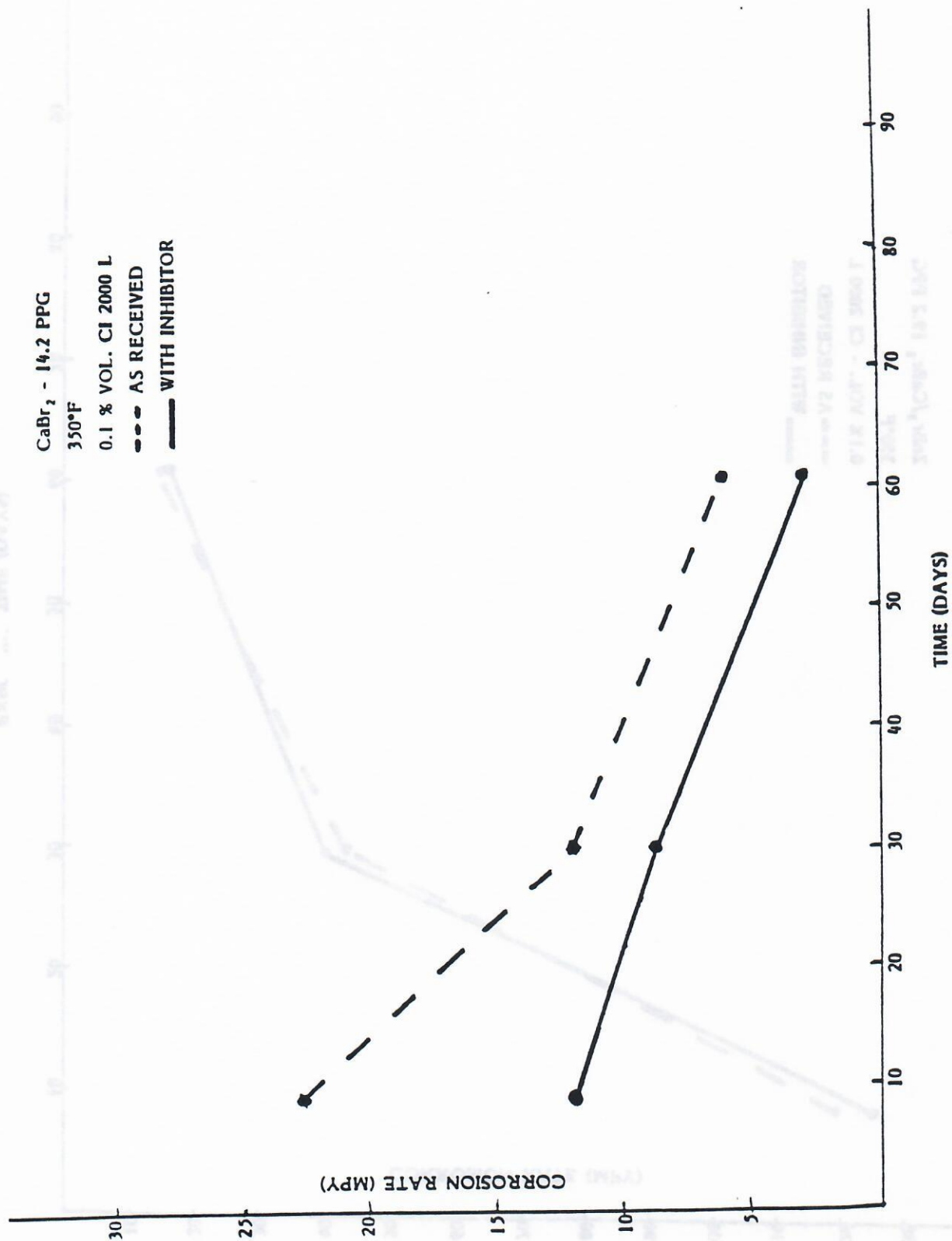


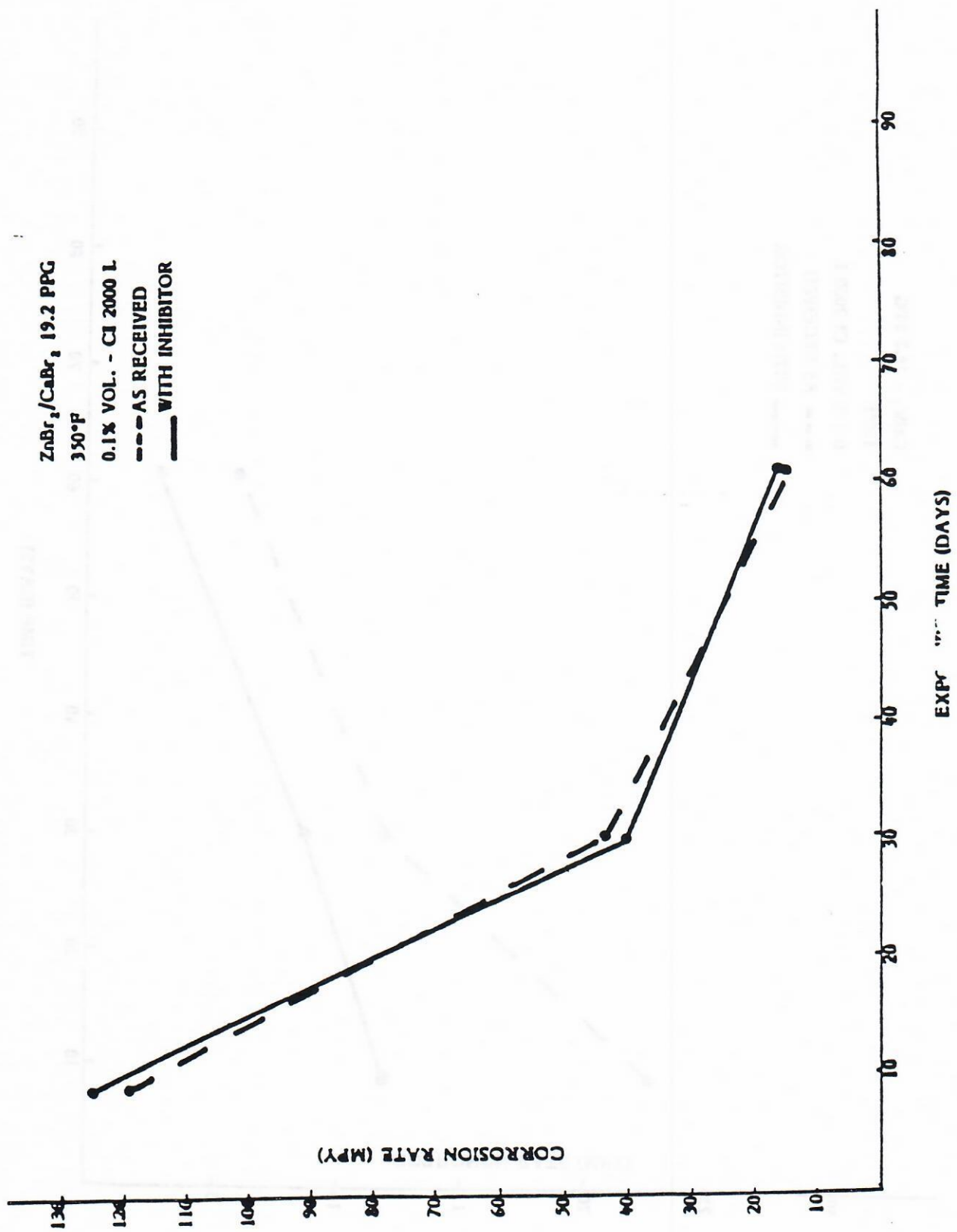
CaBr₂ - 14.2 PPG
350°F

0.1 % VOL. CI 2000 L

--- AS RECEIVED

— WITH INHIBITOR





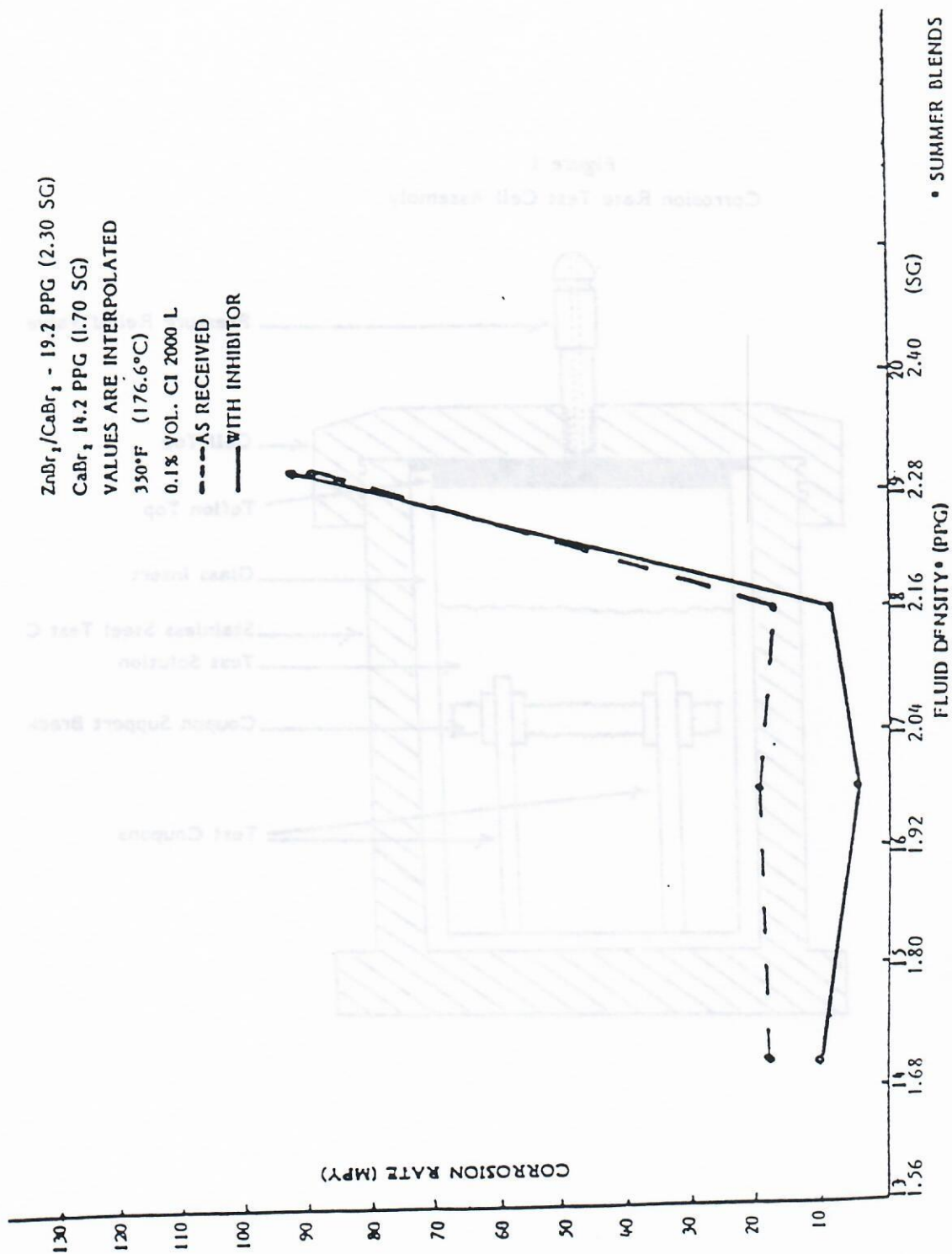
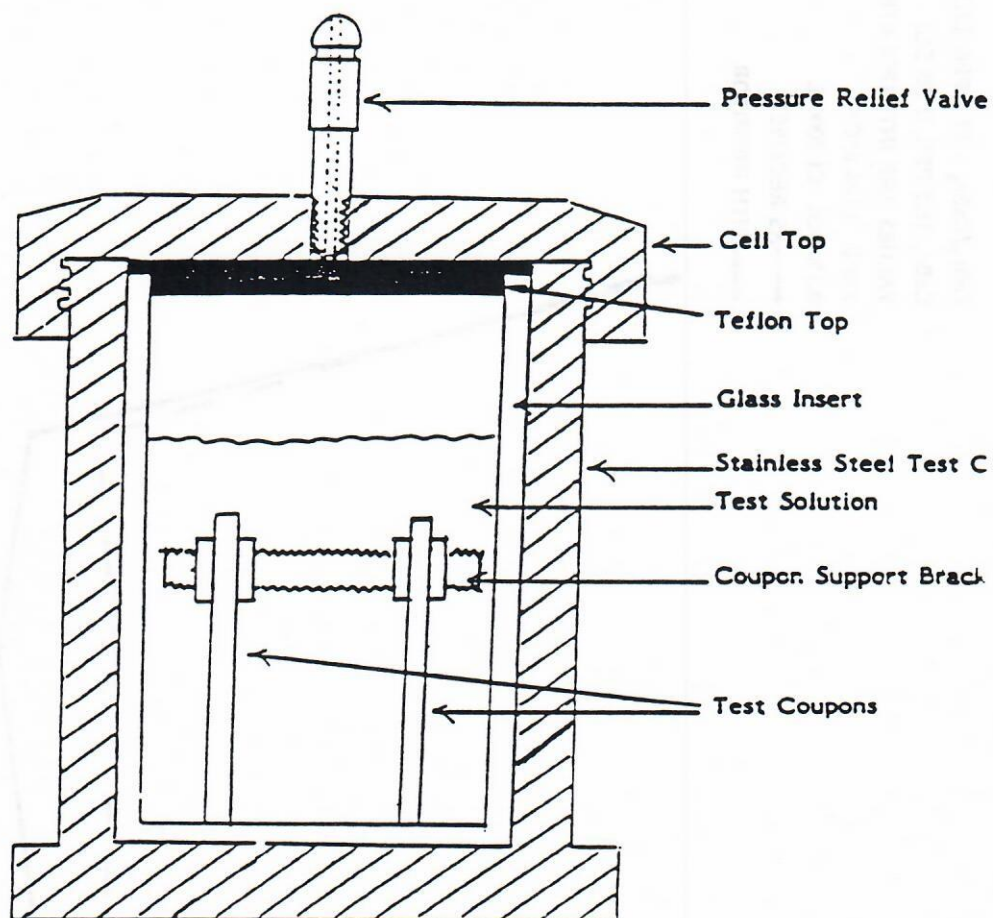


Figure 1
Corrosion Rate Test Cell Assembly



CORROSION RATE CALCULATION

$$\text{CORROSION RATE (mpy)} = \frac{534,000 (\text{Change in weight})}{[\text{SpGr(g/cc)}] [\text{Surface Area (in}^2\text{)}] [\text{Time (hrs)}]}$$

CORROSION RATES OF UNINHIBITED BRINES (mpy)

Brine	Density lb/gal	121°C 250°F			149°C 300°F/500 PSI N ₂			177°C 350°F/500 PSI N ₂			204°C 400°F/500 PSI N ₂		
		1 Day	7 Days	30 Days	1 Day	7 Days	30 Days	1 Day	7 Days	30 Days	1 Day	7 Days	30 Days
NaCl	10.0	3.7*	0.8*	N.T.	3.7	1.4	1.5	4.9	1.7	0.9	No Test		
KCl	9.7	7.28*	1.3*	N.T.	8.8	2.6	1.3	12.4	3.3	1.6	No Test		
NaBr ₂	12.3	3.7	0.9	0.5	6.6	1.0	0.2	14.2	1.0	0.2	No Test		
KBr ₂	11.4	3.7*	0.6*	N.T.	5.3	1.2	0.3	4.3	0.8	0.3	No Test		
CaCl ₂	11.6	5.3	0.8	0.3	10.9	2.2	0.5	29.2	10.0	1.3	54.7	7.7	2.8
CaBr ₂	14.2	11.2	4.9	3.1	20.9	8.9	5.6	46.1	17.5	9.7	76.9	22.0	8.5
ZnBr ₂ / CaBr ₂	19.2	10.2	4.9	7.2	60.4	25.7	23.3	140.0	89.6	28.8	Very High Rates		

Brine Volume/Surface Area - 20 cc/in²

1010 Carbon Steel Coupons

*500 psi N₂

CORROSION RATES OF UNINHIBITED CaCl₂ / CaBr₂ / ZnBr₂ BRINES (mpy) CRYSTALLIZATION TEMPERATURE BELOW 10°F (LCD)

Density lb/gal	121°C 250°F				149°C 300°F/500 PSI N ₂				177°C 350°F/500 PSI N ₂			204°C 400°F/500 PSI N ₂			
	1 Day	7 Days	30 Days	90 Days	1 Day	7 Days	30 Days	1 Day	7 Days	30 Days	1 Day	7 Days	30 Days	90 Days	
15.5	6.8	8.3	2.7	N.T.	19.9	6.4	2.3	52.9	13.3	N.T.	-----	No Test -----			
16.0	9.8	6.3	3.8	2.9	15.2	8.0	4.1	29.1	17.2	10.4	129.6	35.6	16.6	9.7	
16.5	6.1	9.8	4.1	N.T.	15.3	6.8	6.9	20.7	13.7	N.T.	-----	No Test -----			
17.5	9.7	23.8	5.3	N.T.	26.5	11.8	3.1	33.7	26.9	N.T.	127.0	45.3	N.T.	N.T.	
18.0	15.9	11.9	8.9	3.2	47.4	26.0	9.0	48.8	38.7	4.9	145.2	44.0	22.9	12.0	

Brine Volume/Surface Area - 20 cc/in²

1010 Carbon Steel

N.T. - no test

CORROSION RATES OF INHIBITED CaBr_2 / ZnBr_2 BRINES AT 250°F / 1010 CARBON STEEL**

Blend Density lb/gal	Test Duration, Days Corrosion Rate, mpy					
	1	7	30	90	180	360
CaBr_2 , 14.2	7.2	0.9	0.2	0.2	0.1	0.1
* $\text{CaBr}_2/\text{ZnBr}_2$, 16.0	4.9	0.8	0.3	0.3	0.2	0.1
* $\text{CaBr}_2/\text{ZnBr}_2$, 18.0	7.5	1.2	1.3	0.8	0.6	0.7
* $\text{CaBr}_2/\text{ZnBr}_2$, 19.2	12.9	2.8	3.5	4.2	4.2	1.8

* Crystallization temperature below 20°F (LCD)

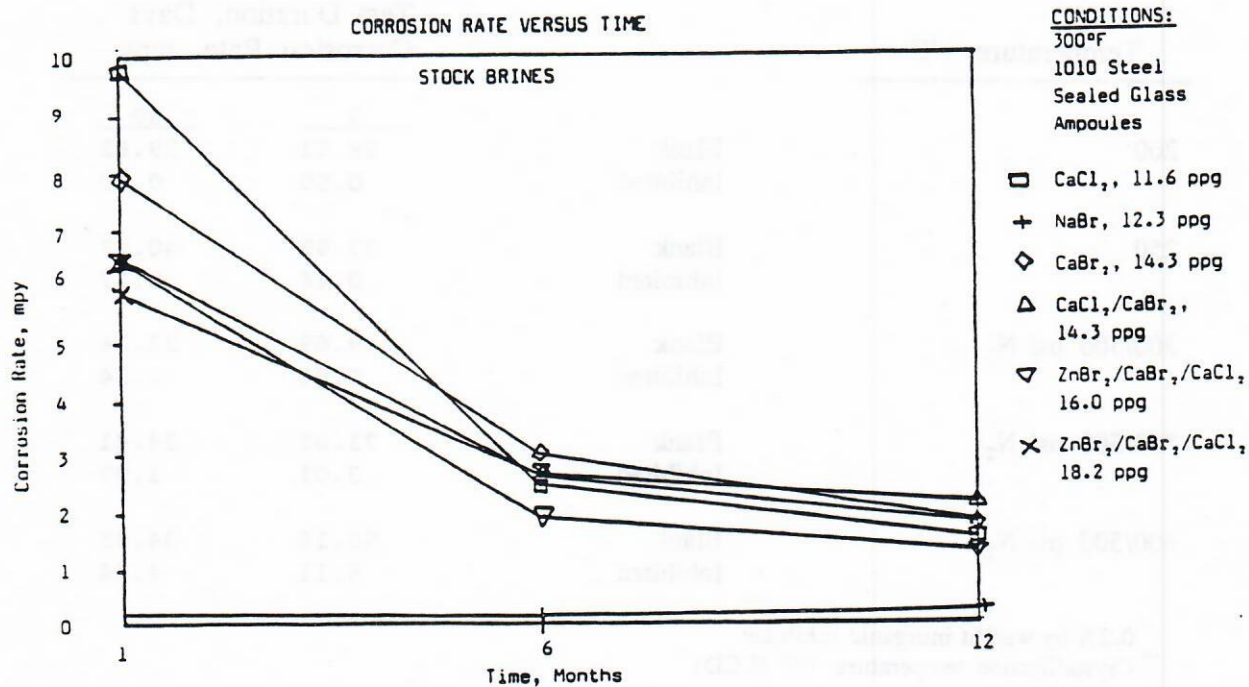
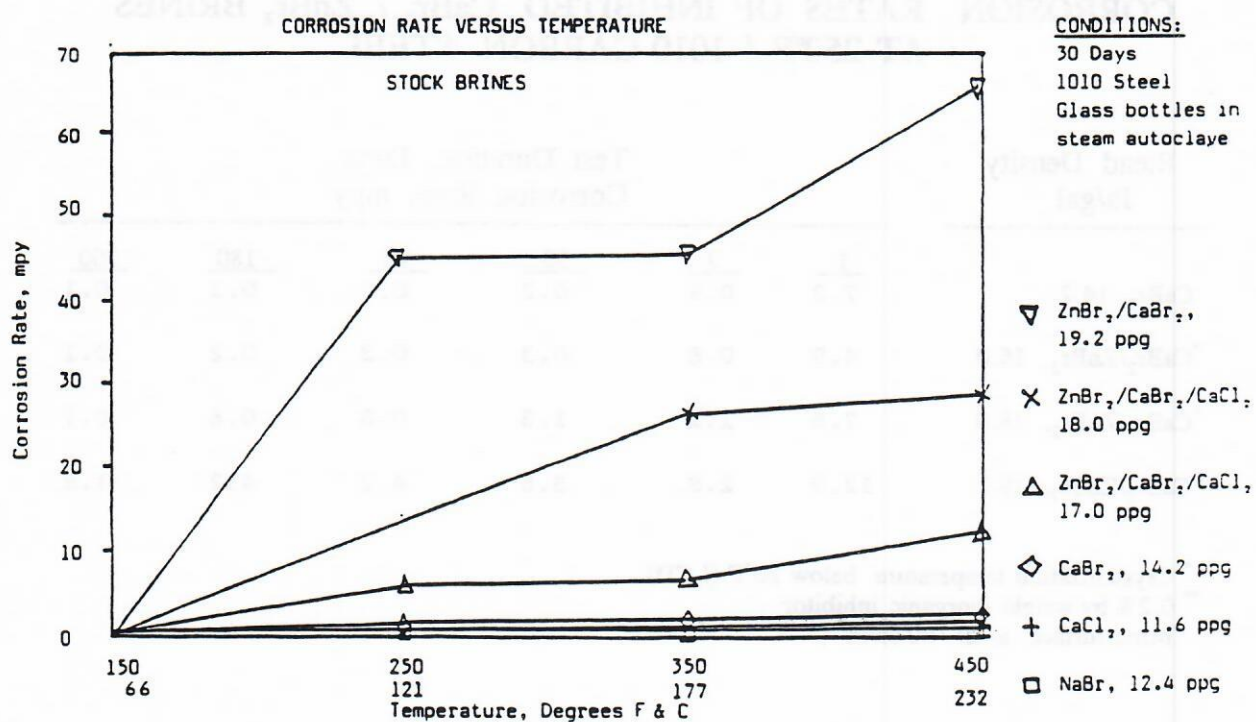
** 0.2% by weight inorganic inhibitor
Brine/surface area: 20 cc/in²

CORROSION RATES OF INHIBITED 18.0 LB/GAL CaBr_2 / ZnBr_2 BRINES N-80 STEEL**

Temperature, °F		Test Duration, Days Corrosion Rate, mpy	
		7	30
200	Blank	28.01	29.62
	Inhibited	0.90	0.30
250	Blank	77.99	40.97
	Inhibited	0.46	0.17
300/500 psi N ₂	Blank	69.69	23.36
	Inhibited	0.81	1.34
350/500 psi N ₂	Blank	71.05	24.41
	Inhibited	3.01	1.97
400/500 psi N ₂	Blank	90.16	34.45
	Inhibited	5.11	4.44

* 0.2% by weight inorganic inhibitor

** Crystallization temperature 9°F (LCD)



GALVANIC CORROSION IN CaCl_2 / CaBr_2 / ZnBr_2 BRINE **30 DAY TEST**

Corroding Metal	Coupled to		Corrosion Rate, mpy	
			15.5 lb/gal 93°C (200°F)	**17.5 lb/gal 149°C (300°F)
N-80	N-80	Blank	2.800	11.10
		*Inhibited	0.250	6.20
N-80	*** SS420	Blank	3.300	11.80
		*Inhibited	0.390	6.20
SS420	N-80	Blank	0.100	0.25
		*Inhibited	0.080	0.25
SS420	SS420	Blank	0.080	0.25
		*Inhibited	0.007	0.24

- * 0.2% by weight inorganic inhibitor
- ** 500 psi N_2
- *** SS420 ~ Cr13

RESULTS: Inhibitor reduced corrosion rate considerably and Galvanic acceleration was not evident.

CORROSION RATE OF *INHIBITED CaBr_2 / ZnBr_2 BRINE**
13CR Stainless Steel
177°C (350°F) / 500 psi N_2

16 ppg	Blank	2.5
	Inhibited	1.3
18 ppg	Blank	3.1
	Inhibited	1.3
19.2 ppg	Blank	3.9
	Inhibited	1.2

- * 0.2% by weight inorganic inhibitor
** Crystallization temperature below -7°C (20°F) (LCTD)

OTHER TEST RESULTS

1. 304SS tested in 14.2 ppg CaBr_2 for 3 days @ 204°C (400°F).
No indication of SCC (stress corrosion cracking).
2. CR13 and CR22 were stressed (C-Ring) to 100% of nominal yield strength in 11.6 and 14.2 ppg fluids for 14 days without and evidence of SCC.

CO₂ SERVICE*

INCREASING RESISTANCE TO CORROSION →

L-80	9 Cr-1 Mo.	22-25 Cr	PROPRIETARY
N-80	13 Cr	(AUSTENITIC / FERRITIC-DUPLEX)	HIGH ALLOY STAINLESS SANICRO 28 INCOLOY INCONEL HASTELLOY C MP35N

* All material may be suitable under specific conditions

H₂S SERVICE*

INCREASING RESISTANCE TO SSC →

V-150	P110	9 Cr-1 Mo 13 Cr	N-80	22-25 Cr 140 ksi	22-25 Cr 110 ksi	L-80 C-75	PROPRIETARY 90 ksi GRADES
						K-55	HIGH ALLOY STAINLESS
						H-40	SANICRO 28 INCOLOY INCONEL HASTELLOY C MP35N

* All material may be suitable under specific conditions

CHLORIDE OR BRINE SERVICE*

INCREASING RESISTANCE TO CSSC AND PITTING



304 STAINLESS STEEL
316 STAINLESS STEEL
410 STAINLESS STEEL
13 Cr-1
9 Cr-1 Mo

22-25 Cr
HASTELLOY C**
MP35N*

SANICRO 28
INCOLOY
INCONEL
HASTELLOY C
MP35N

-
- * All material may be suitable under specific conditions.
** Depends on heat treatment.

ADDITIVES FOR BRINES

VISCOSIFIERS

VISCOSITY BREAKERS

CORROSION INHIBITORS

SPACERS FOR MUD DISPLACEMENT

OXYGEN SCAVENGERS

BACTERICIDES

FLUID-LOSS CONTROL AGENTS

DEFOAMERS

VARIABLES AFFECTING PV / YP AND GEL STRENGTH

BOTTOMHOLE TEMPERATURE

CONCENTRATION OF ADDITIVES

OPERATOR REQUIREMENTS

SOLIDS CONTENT

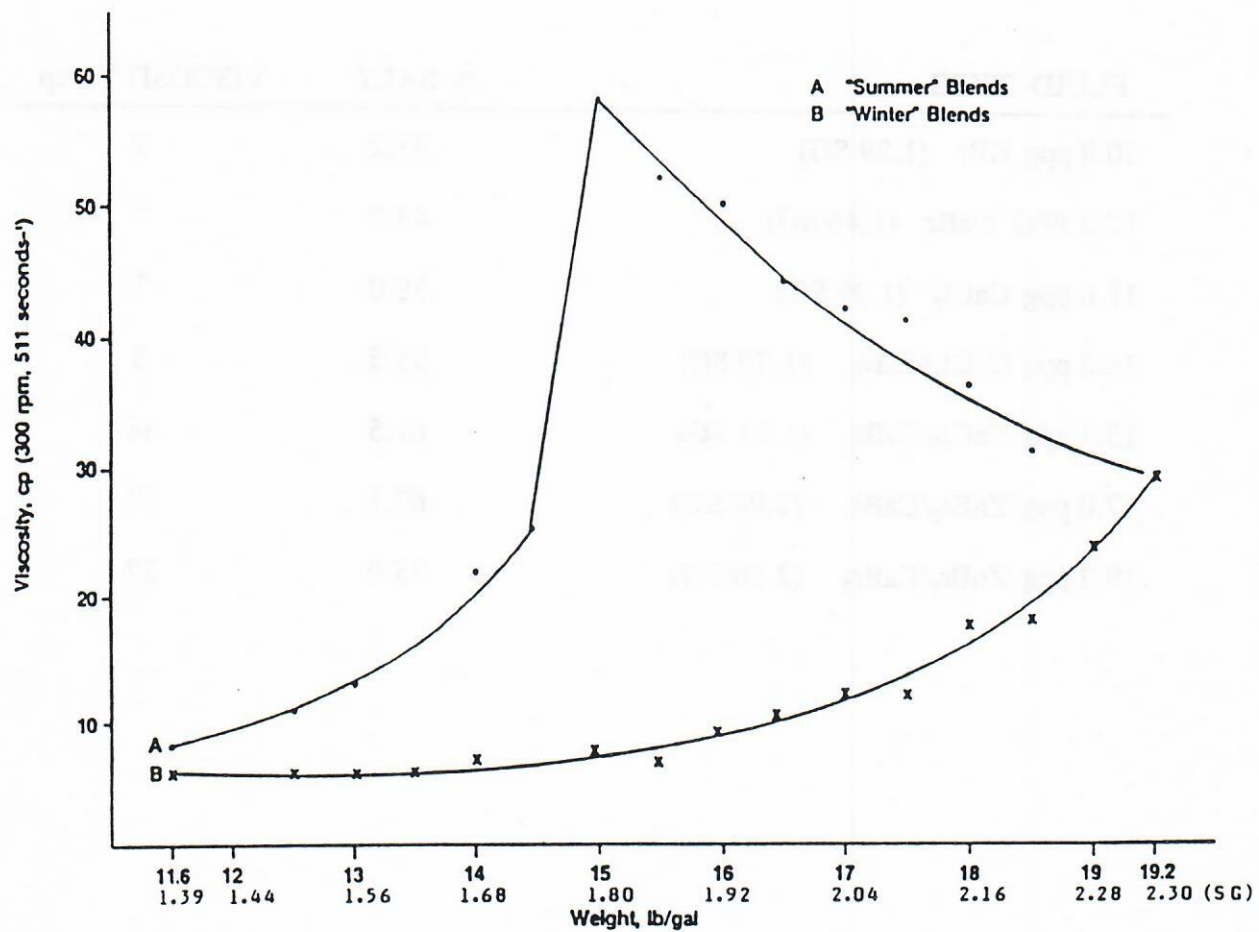
HOLE CONDITIONS

DENSITY CHANGES

VOLUME CHANGES

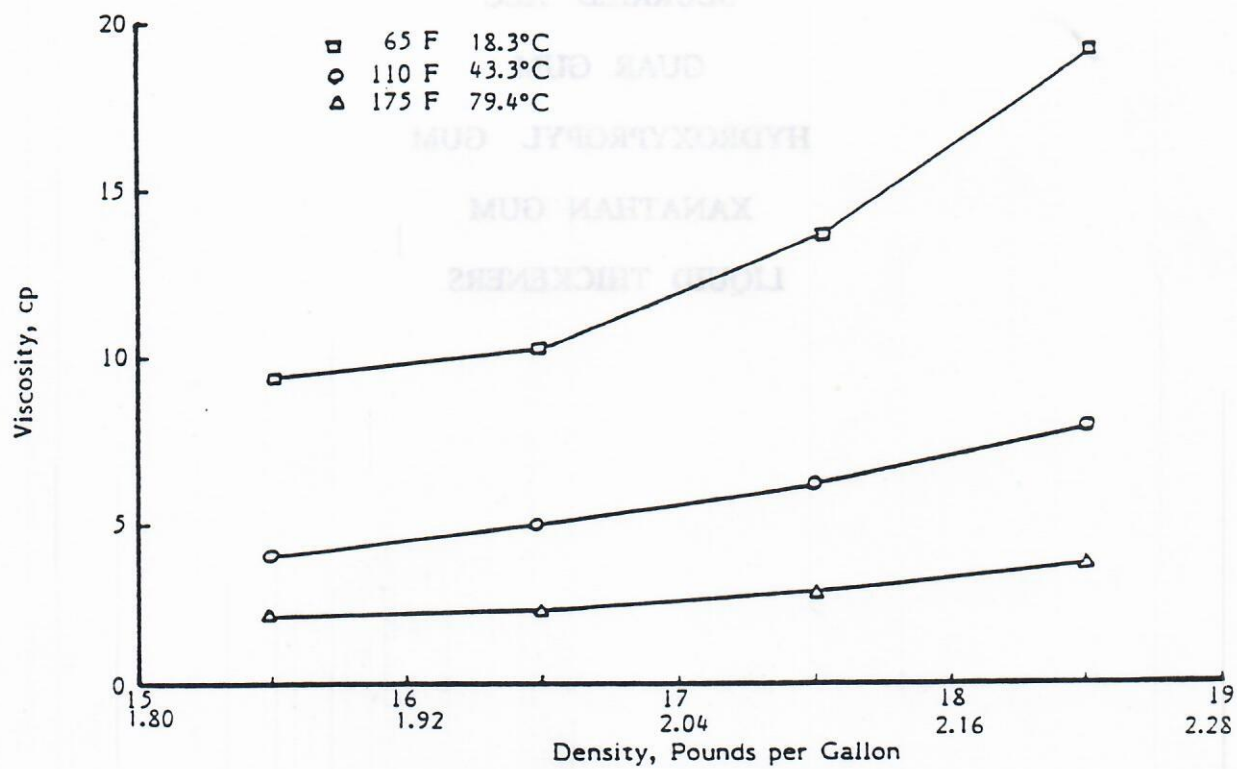
NATURAL VISCOSITIES AND TYPICAL CLEAR BRINE FLUIDS

FLUID TYPE	% SALT	VISCOSITY, cp
10.8 ppg KBr (1.29 SG)	33.2	2
12.2 PPG NaBr (1.46 SG)	43.2	2
11.6 ppg CaCl ₂ (1.39 SG)	38.0	7
14.2 ppg CaCl ₂ /CaBr ₂ (1.70 SG)	53.5	8
15.1 ppg CaCl ₂ /CaBr ₂ (1.81 SG)	61.5	38
17.0 ppg ZnBr ₂ /CaBr ₂ (2.04 SG)	67.1	12
19.2 ppg ZnBr ₂ /CaBr ₂ (2.30 SG)	75.0	27



Viscosities of "summer" and "winter" brines containing CaCl_2 , CaBr_2 and/or ZnBr_2 .
 No viscosifier added.

Viscosity of CaBr_2 - ZnBr_2 at Various Temperatures



TYPES OF VISCOSIFIERS

POWDER HYDROXYETHYLCELLULOSE (HEC)

SLURRIED HEC

GUAR GUM

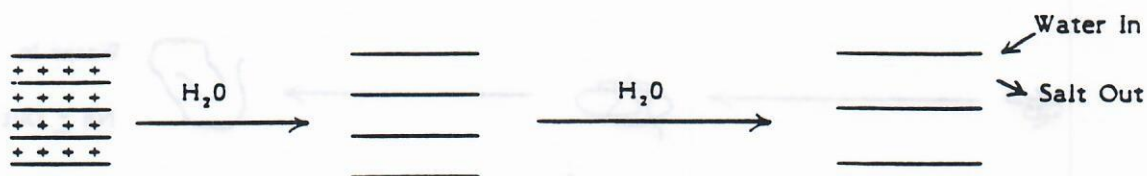
HYDROXYPROPYL GUM

XANATHAN GUM

LIQUID THICKENERS

SWELLING AND DISPERSION OF CLAYS AND POLYMERS

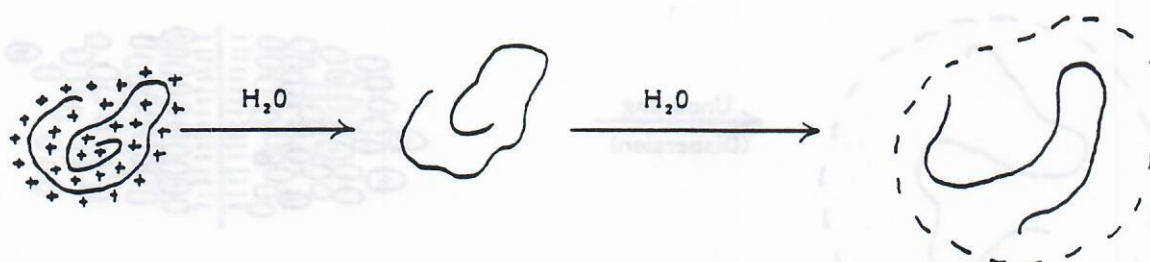
(Freshwater)



- Non-Hydrated Aggregate

- Ionization and Hydration of Clay-Shale Surface (Crystalline Swelling)
- Increasing Platelet Spacing

- Osmotic Diffusion of Counter-ions into fresh water
- Dispersion and Generation of Water Envelope

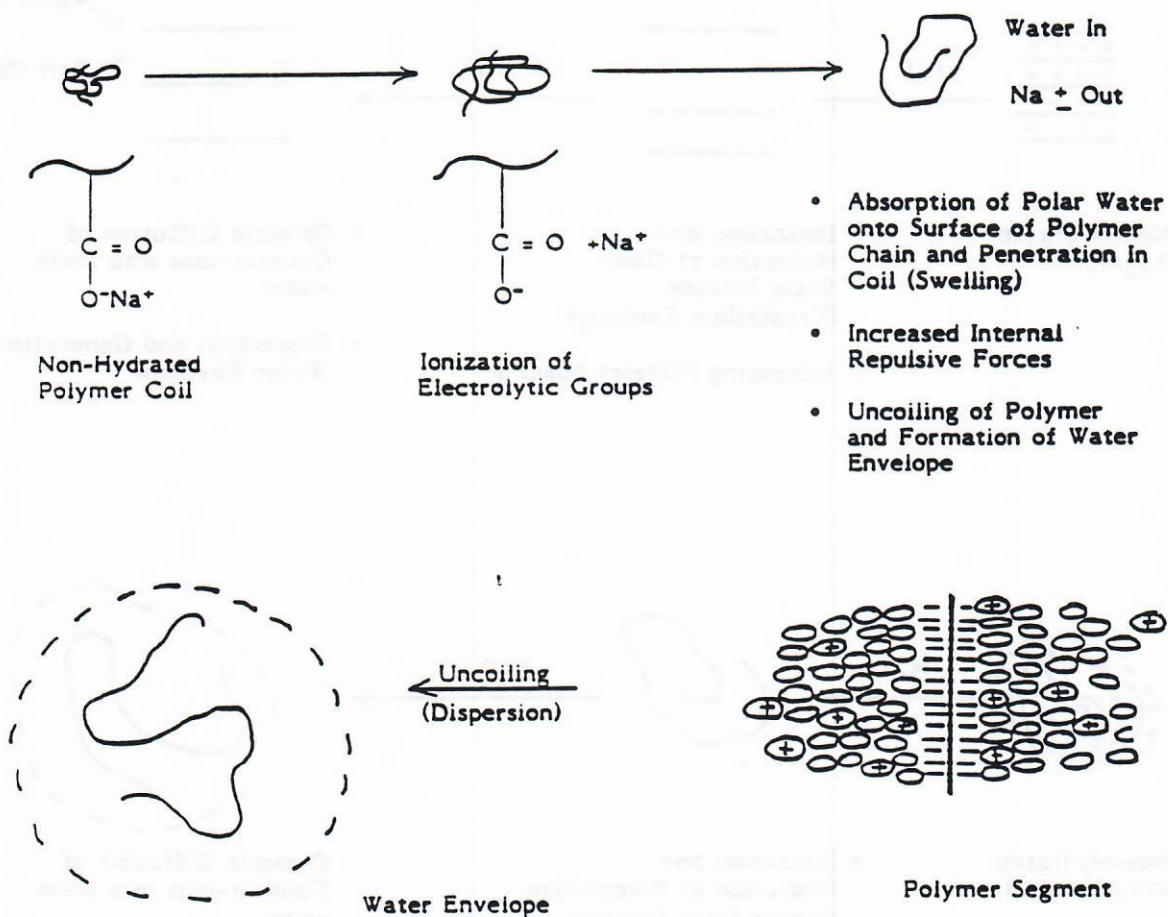


- Non-Hydrated Polymer Coil

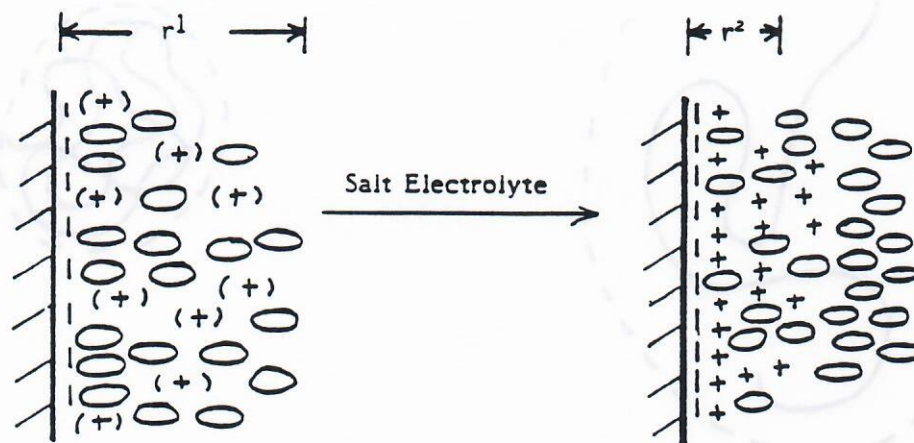
- Ionization and Hydration of Electrolyte Groups from Polymer Surface
- Polymer uncoils

- Osmotic Diffusion of Counter-ions into fresh water
- Dispersion and Generation of Water Envelope

SWELLING AND DISPERSION OF WATER SOLUBLE POLYMER (Polymer Swelling & Dispersion)



THE ELECTROSTATIC DOUBLE LAYER OF POLYMERS IN
AQUEOUS SOLUTIONS OF ANIONIC POLYELECTROLYTES



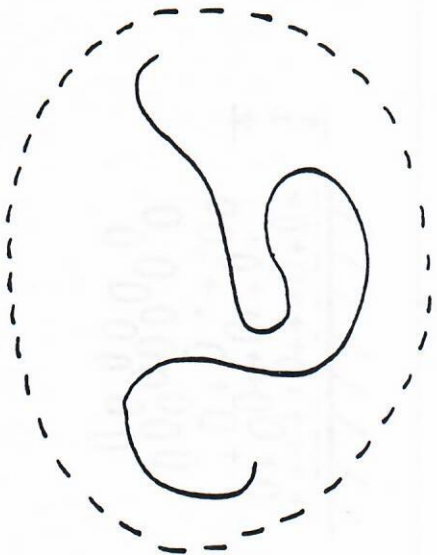
Fresh Water

- Diffused Double Layer
- Good Polymer Solubility
- Good Polymer-Solution Viscosity

Salt Water Solution

- Compressed Double Layer
- High Cation (counterion) Concentration at Polymer Surface
- Reduced polymer Solubility Due to Dehydration
- Reduced Viscosity Due to Decrease in "Bound-Water" Envelope Size.

COUNTER-IONS EFFECTS



Fresh Water

Low Concentration of Counter-Ions
In Water Envelope
(High Viscosity)



Salt Water

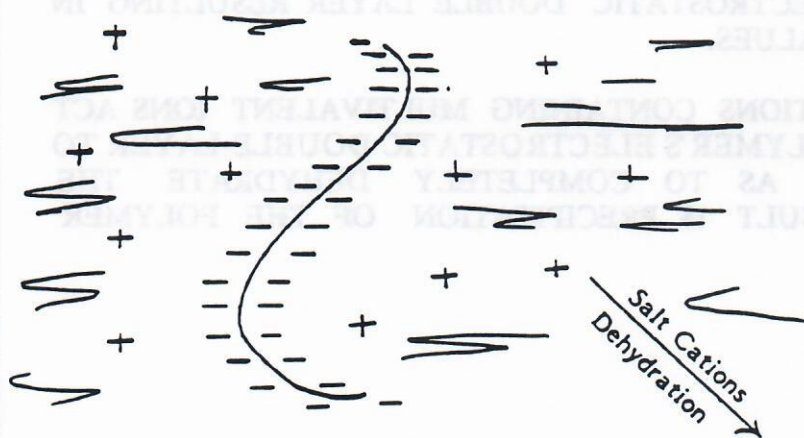
High Concentration of Counter-Ions
at the Surface of Polymer (Reduce
Viscosity)

The Counter-Ions Compete with Water Molecules
for Bond Sites on the Polymer Chain and Cause
Dehydration of the Polymer and Coiling Results.

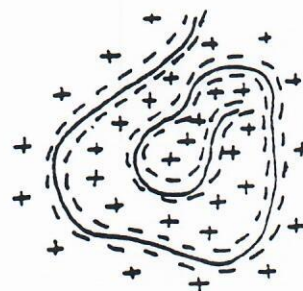
SWELLING AND DISPERSION OF CLAYS AND POLYMERS

Effect of Salt Counter-ions on Polyelectrolyte Activity

Polyelectrolyte in Fresh Water
Produces Large Water Envelopes
Good Polymer Solubility, and
High Viscosity Values.



High Concentration of Salt Counter-ions
at Polymer Surface Compresses Water
Envelope, Increases Coiling, Decreases
Solubility, and Decreases Viscosity.



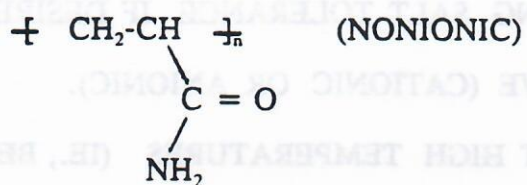
THE ELECTROSTATIC DOUBLE LAYER AND POLYMER SOLUBILITY

- ° COMPRESSING THE ELECTROSTATIC DOUBLE LAYER LOWERS SOLUBILITY.
- ° AQUEOUS SALT SOLUTIONS CONTAINING MONOVALENT IONS ACT TO COMPRESS THE ELECTROSTATIC DOUBLE LAYER RESULTING IN LOWER VISCOSITY VALUES.
- ° AQUEOUS SALT SOLUTIONS CONTAINING MULTIVALENT IONS ACT TO COMPRESS THE POLYMER'S ELECTROSTATIC DOUBLE-LAYER TO SUCH AN EXTENT AS TO COMPLETELY DEHYDRATE THE MOLECULE. THE RESULT IS PRECIPITATION OF THE POLYMER FROM SOLUTION.

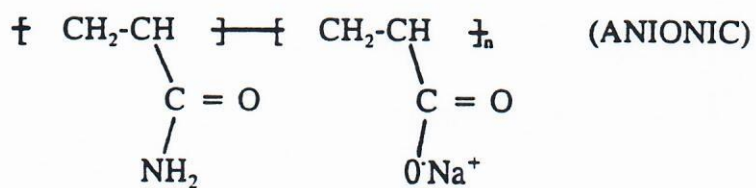
EXAMPLES OF WATER SOLUBLE POLYMERS

SYNTHETIC PRODUCTS

- POLYACRYLAMIDE (HOMOPOLYMER)



- POLYCRYLAMIDE - CO - POLY (SODIUM ACRYLATE) (COPOLYMER)



EFFECTIVE TEMPERATURE - STABLE POLYELECTROLYTES

AN EFFECTIVE TEMPERATURE - STABLE POLYELECTROLYTE SHOULD:

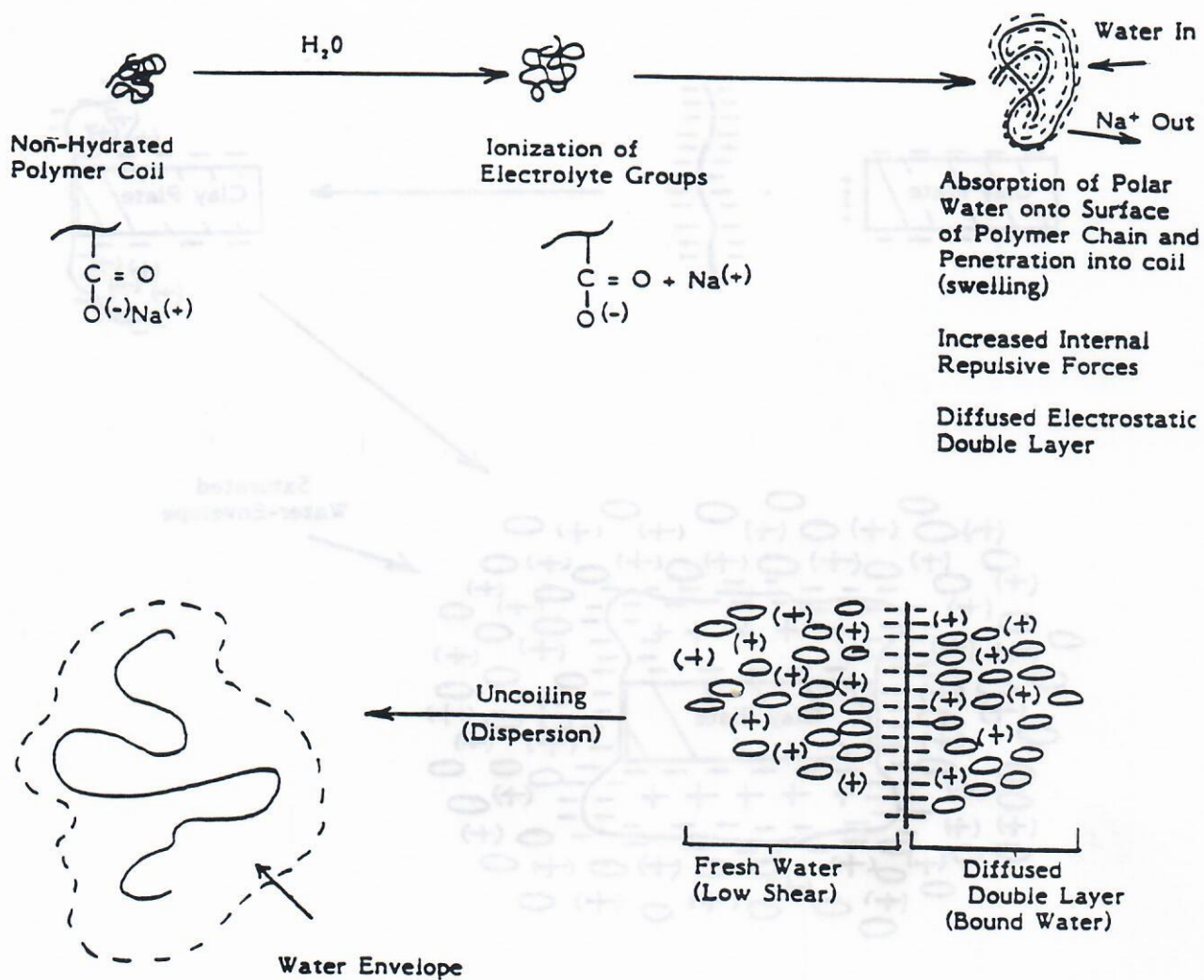
BE CONSTRUCTED FROM HEAT - STABLE, WATER SOLUBLE MONOMERS (HAVING SALT TOLERANCE IF DESIRED).

BE SURFACE ACTIVE (CATIONIC OR ANIONIC).

RESIST COILING AT HIGH TEMPERATURES (IE., BE STIFF).

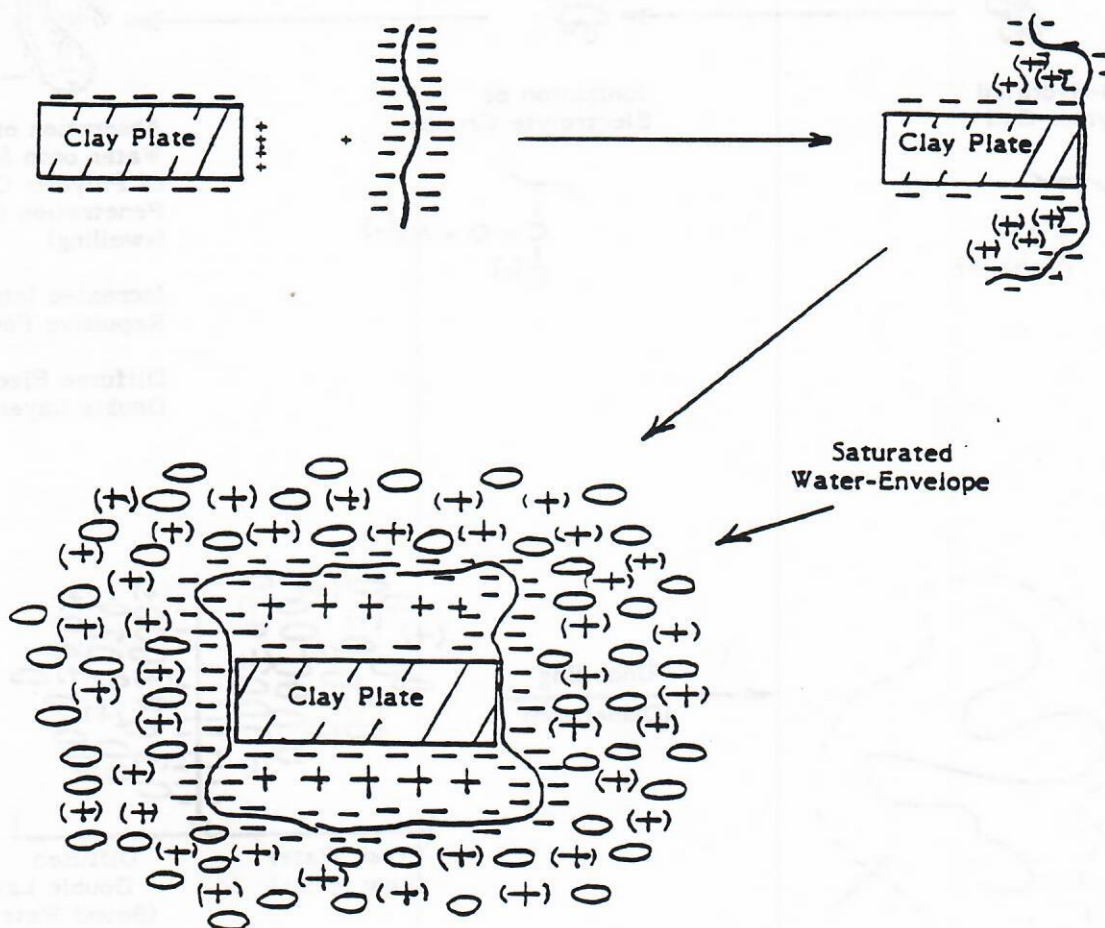
EXHIBIT A HIGH DEGREE OF INTRAMOLECULAR PEPTIDE INTERACTION.

FLUID VISCOSIFIER



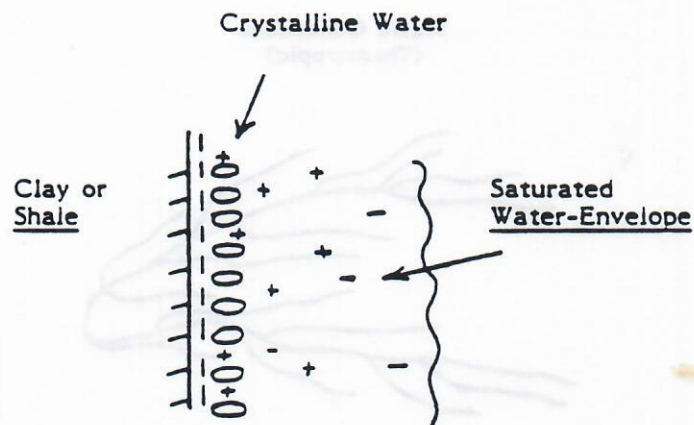
The "Bound" Water-Envelope Resists Flow and Therefore Accounts for Viscous Nature of Fluid. Changes in Fluid Viscosity Result from Changes in Water-Envelope.

SHALE STABILIZER



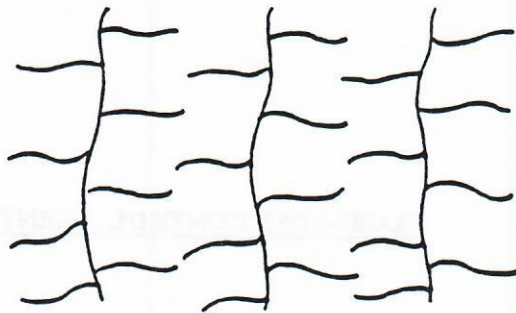
The Saturated Water-Envelope and Ionic Double Layer
Acts as a Barrier to Retard Osmotic Swelling
and Enhance Deflocculation.

FLUID-LOSS CONTROL AGENT

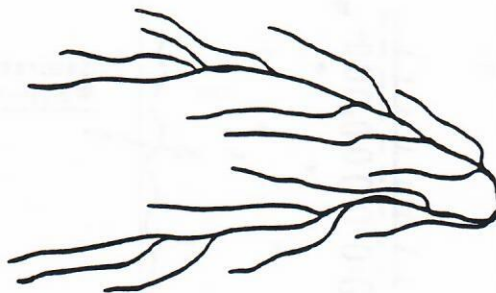


A Saturated Water-Envelope Will Resist
Absorption of Additional Water Molecules
and - because of the "Bound-Water" Layer
Prevents Migration of Water into the
Clay-Shale Structure.

XANTHAN GUM



Static Conditions
(Thixotropic)



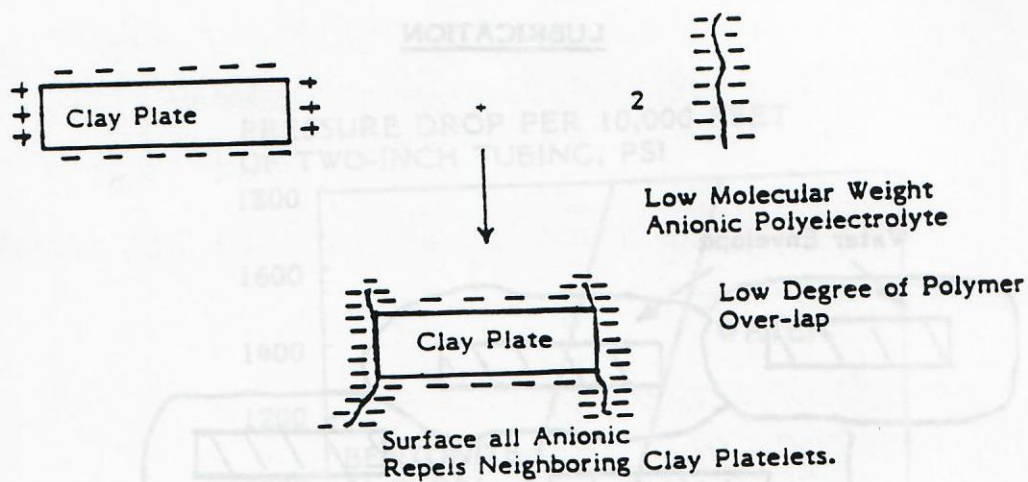
Dynamic Conditions
(Pseudoplastic & Shear Thinning)

MECHANISM OF SUSPENSION BY XANTHAN GUM

Under dynamic conditions, aqueous solutions of Xanthan Gum exhibit pseudoplastic behavior (ie., shear thinning).

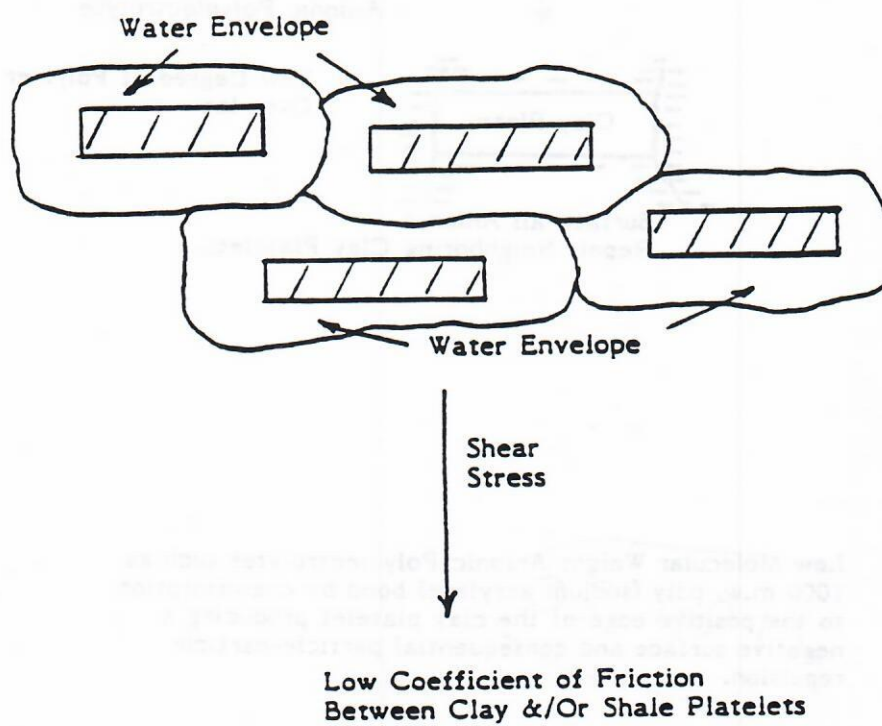
Under static conditions, aqueous solutions of Xanthan Gum become Thixotropic (ie., provides gel strength).

THINNING & DISPERSION



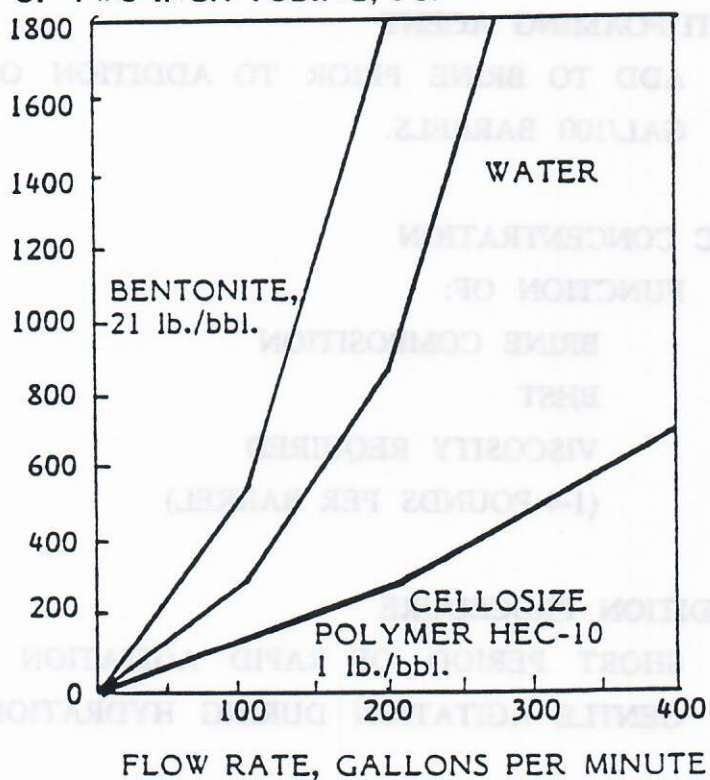
Low Molecular Weight Anionic Polyelectrolytes such as 1000 m.w. poly (sodium acrylate) bond by chemisorption to the positive edge of the clay platelet producing a negative surface and consequential particle-particle repulsion.

LUBRICATION



HYDRODYNAMIC FRICTION REDUCTION WITH CELLOSIZE POLYMER HEC-10

PRESSURE DROP PER 10,000 FEET
OF TWO-INCH TUBING, PSI



HEC VISCOSIFIER

DRY FORM

DISPERSE & PREHYDRATE IN:

50:50 RATIO OF FRESHWATER AND MUTUAL SOLVENT. (USE
WITHIN 10 MINUTES).

ANTI FOAMING AGENT

ADD TO BRINE PRIOR TO ADDITION OF HEC SLURRY 5
GAL/100 BARRELS.

HEC CONCENTRATION

FUNCTION OF:

BRINE COMPOSITION

BHST

VISCOSITY REQUIRED

(1-4 POUNDS PER BARREL)

ADDITION PROCEDURE

SHORT PERIOD OF RAPID AGITATION FOR DISPERSION
GENTLE AGITATION DURING HYDRATION

CALCIUM BROMIDE AND ZINC BROMIDE

HEAT MAY BE REQUIRED FOR SURFACE HYDRATION
CIRCULATE THRU CHOKE OR PARTIALLY CLOSED VALVE

PREMIXED PILLS

STORE ON LOCATION

Figure 1: Viscosity Performance of VI 2000 D

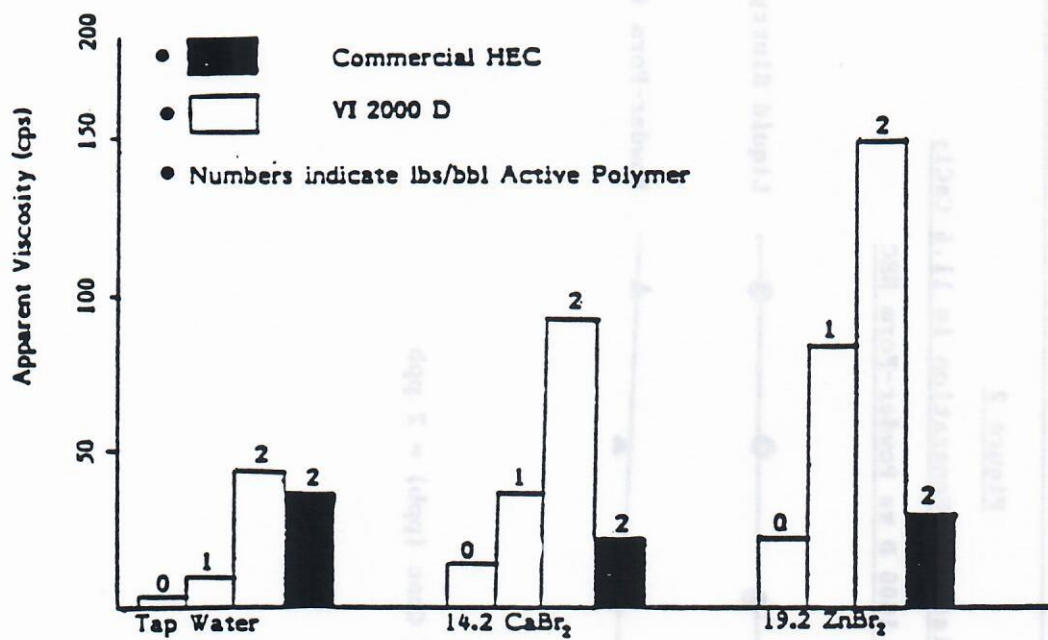
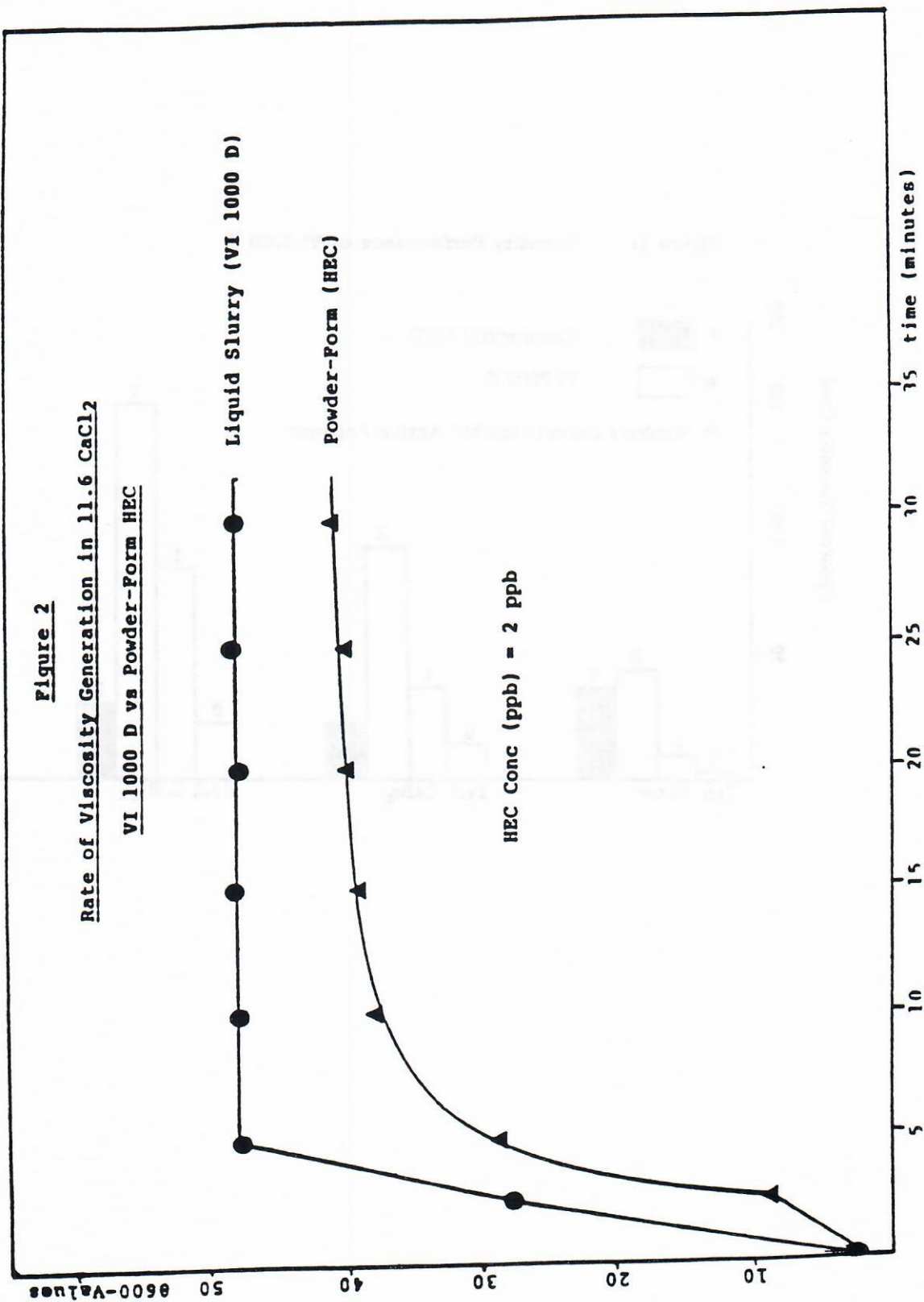


Figure 2

Rate of Viscosity Generation in 11.6 CaCl₂

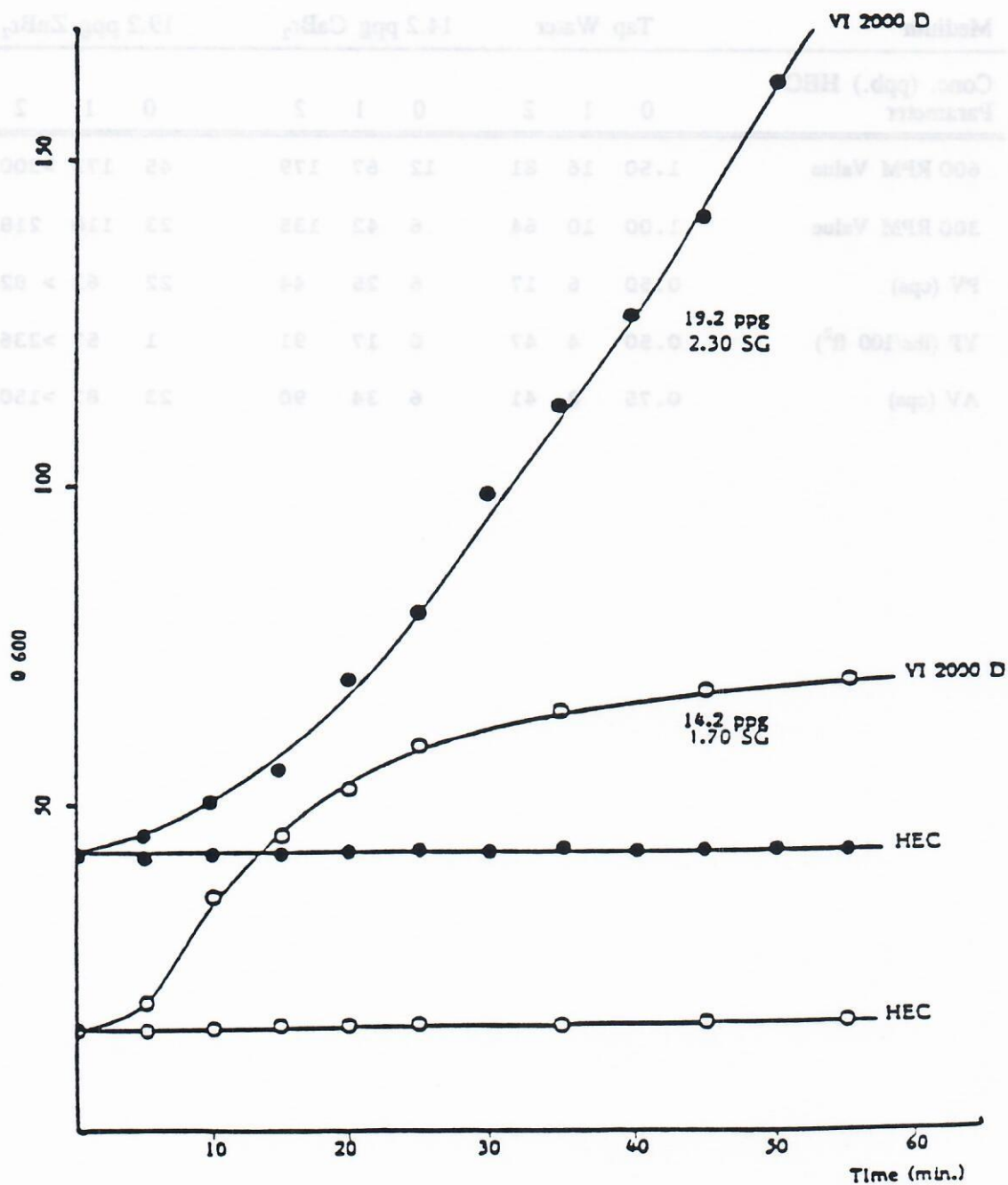
VI 1000 D vs Powder-Form HEC



HEC Conc (ppb) = 2 ppb

VISCOSITY OF PREDISPERSED PLOYMER VS. DRY POLYMER

Ease of Mixing



RHEOLOGY OF SELECTED AQUEOUS MEDIA TREATED WITH VI 2000 D

Medium	Tap Water			14.2 ppg CaBr ₂			19.2 ppg ZnBr ₂		
Conc. (ppb.) HEC Parameter	0	1	2	0	1	2	0	1	2
600 RPM Value	1.50	16	81	12	67	179	45	173	>300
300 RPM Value	1.00	10	64	6	42	135	23	110	218
PV (cps)	0.50	6	17	6	25	44	22	63	> 82
YP (lbs/100 ft ²)	0.50	4	47	0	17	91	1	57	>236
AV (cps)	0.75	8	41	6	34	90	23	87	>150

EFFECT OF BRINE COMPOSITION ON VISCOSITY

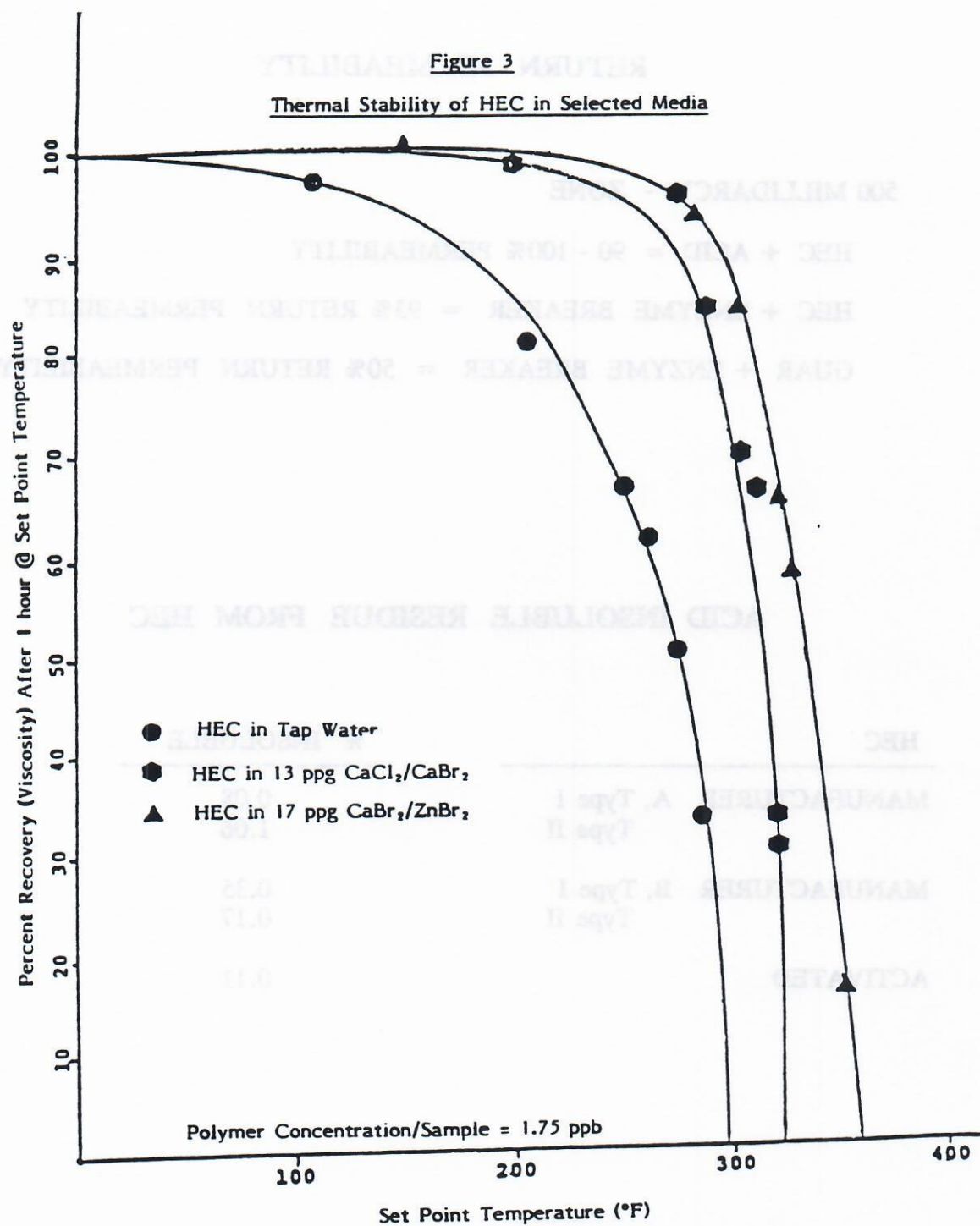
Brine Density lb/gal		Composition	Viscosity*, cp (300 rpm)	
			1 HR. @ 74°F (23°C)	16 HR. @ 150°F (68°C)
14.5	1.74 (SG)	A	28	59
14.5	1.74 (SG)	B	47	90
14.5	1.74 (SG)	C	65	106
15.0	1.80 (SG)	A	21	38
15.0	1.80 (SG)	B	64	95
15.0	1.80 (SG)	C	91	138
15.5	1.86 (SG)	A	23	38
15.5	1.86 (SG)	B	70	109
15.5	1.86 (SG)	C	58	148
16.0	1.92 (SG)	A	52	73
16.0	1.92 (SG)	B	46	130
16.0	1.92 (SG)	C	55	156

* 1.5 LB/BBL ACTIVATED HEC ADDED

ACTIVATED HEC IN SEVERAL CONVENTIONAL HEAVY BRINES

Brine Density lb/gal			Salts Present in Brine ¹			3 lb/bbl HEC Fann 300 rpm Viscosity	
			CC	CB	ZN	1 Hr. @ 74°F (23°C)	16 Hr. @ 150°F (68°C)
15.0	1.80	(SG)	X	X		291	300
15.1	1.81	(SG)	X	X	X	29	29
15.5	1.86	(SG)	X	X	X	28	26
16.0	1.92	(SG)	X	X	X	25	24
16.5	1.98	(SG)	X	X	X	28	175
17.0	2.04	(SG)	X	X	X	38	160
17.5	2.10	(SG)	X	X	X	75	>300
18.0	2.16	(SG)	X	X	X	158	>300
18.5	2.22	(SG)	X	X	X	>300	>300
15.0	1.80	(SG)		X	X	7	14
15.3	1.83	(SG)		X	X	10	37
15.5	1.86	(SG)		X	X	48	222
16.0	1.92	(SG)		X	X	127	>300
16.5	1.98	(SG)		X	X	154	>300
17.0	2.04	(SG)		X	X	197	>300
17.5	2.10	(SG)		X	X	>300	>300

¹ CC=Calcium Chloride. CB=Calcium Bromide. ZN=Zinc Bromide



RETURN PERMEABILITY

500 MILLIDARCY - ZONE

HEC + ACID = 90 - 100% PERMEABILITY

HEC + ENZYME BREAKER = 93% RETURN PERMEABILITY

GUAR + ENZYME BREAKER = 50% RETURN PERMEABILITY

ACID INSOLUBLE RESIDUE FROM HEC

HEC	% INSOLUBLE
MANUFACTURER A, Type I	0.08
Type II	1.06
MANUFACTURER B, Type I	0.35
Type II	0.17
ACTIVATED	0.11

VISCOSITY BREAKERS

**OXIDIZERS
FREE RADICAL GENERATORS
ACID
ENZYMES***

BREAKERS THAT GENERATE BROMINE

**HYPOCHLORITE
PERSULFATE**

* ENZYMES DO NOT BREAK HEC VISCOSIFIED HEAVY BRINES

REDUCING VISCOSITY

**CALCIUM HYPOCHLORITE (SWIMMING POOL CHLORINE)
(0.1 - 0.4 LBS./POUND OF HEC)**

SOLUTION:

MIX 5 - 8 LBS. CALCIUM HYPOCHLORITE PER GALLON OF WATER

DANGER:

**ADD BELOW SURFACE OF BRINE TO PREVENT CHLORINE OR
BROMINE LIBERATION INTO ATMOSPHERE.**

STORE AWAY FROM COMBUSTIBLE ORGANIC MATERIAL

CONCLUSIONS

1. Viscosity of brine depends on quantity of salt & mixture of salt contained in brine.
2. Ability to viscosify heavy brines with HEC depends on salt composition of brines.
3. Brine preparation procedures affect viscosity when using HEC.
4. Any density from 11.6 - 19.2 ppg can be viscosified with activated HEC.*
5. Use of activated HEC allows preparation of viscosified brines at ambient temperature. Heat is not required (change formulation).
6. Activated HEC greatly reduces time necessary to prepare viscosified heavy brines.
7. Brines of any viscosity can be prepared using activated HEC.
8. Any type of HEC can be activated.
9. Brine viscosified with activated HEC is pseudoplastic. Shear thinning.
10. Less activated HEC is required to generate the same viscosity as with powdered HEC.

* Composition will vary for a given density (see number 2).

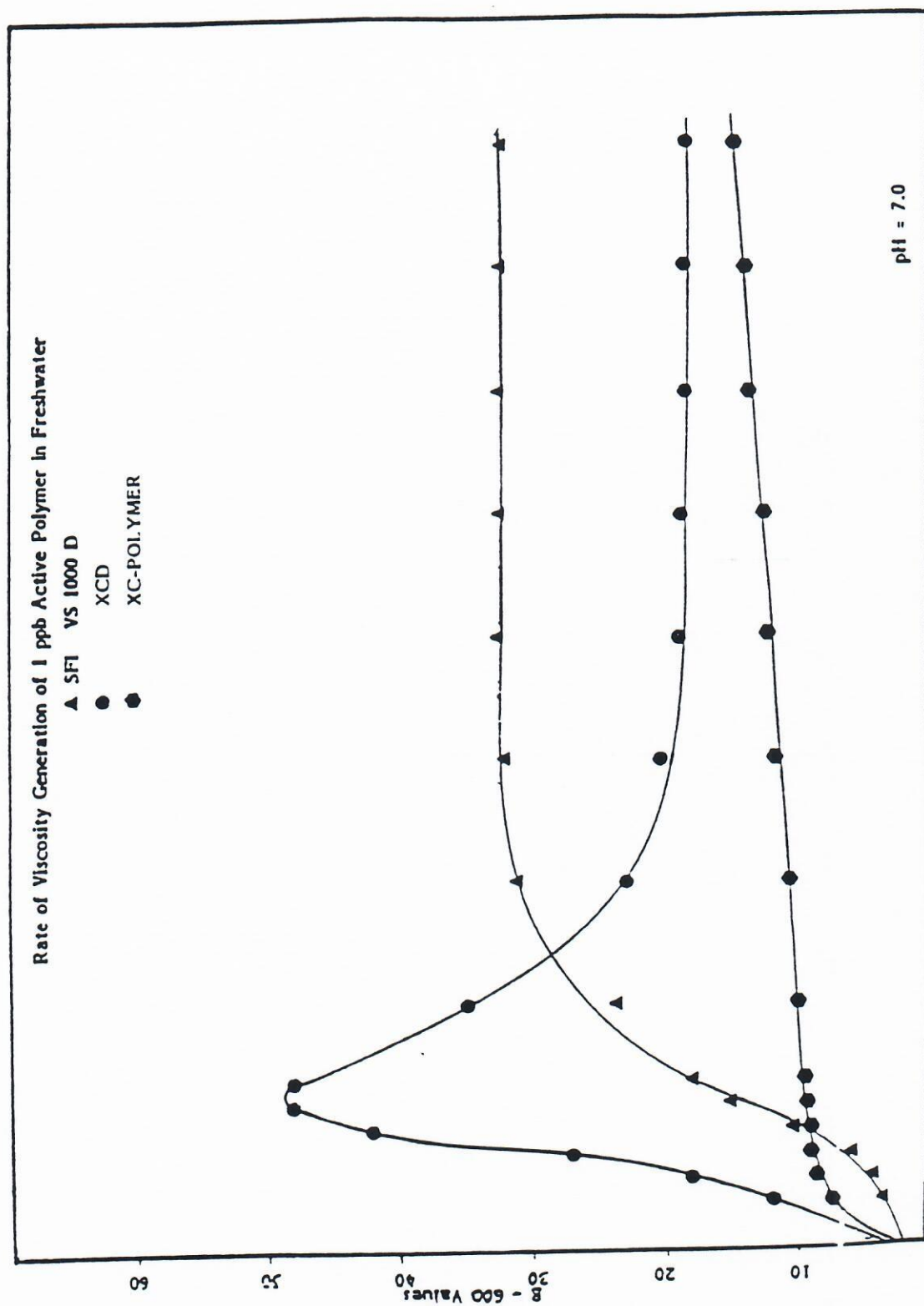




Table 2.1

SODIUM CHLORIDE SOLUTION REQUIREMENTS
USED SAGD NACL (100%)

To make 1 M (42 gal)

Brine Density at 100 °F	Water lb	100% NaCl lb	Concentration Factor (ACTIV) °F
8.4	398	4	+21
8.5	397	8	+20
8.6	396	12	+19
8.7	394	22	+18
8.8	392	28	+17
8.9	390	32	+16
9.0	387	42	+15
9.1	385	47	+14
9.2	382	52	+13
9.3	379	62	+12
9.4	376	68	+ 8
9.5	373	74	+ 8
9.6	370	82	+ 2
9.7	368	88	- 2
9.8	365	92	- 2
9.9	362	102	+ 2
10.0	359	108	+12

BRINE TABLES

Table 3.1

SODIUM CHLORIDE SOLUTION REQUIREMENTS
USING SACKED NaCl (100%)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	Water bbl	100% NaCl lb	
8.4	.998	4	+31
8.5	.993	9	+29
8.6	.986	16	+27
8.7	.981	22	+26
8.8	.976	28	+24
8.9	.969	35	+22
9.0	.962	41	+19
9.1	.955	47	+17
9.2	.948	54	+14
9.3	.940	61	+11
9.4	.933	68	+ 9
9.5	.926	74	+ 6
9.6	.919	81	+ 3
9.7	.910	88	- 1
9.8	.902	95	- 5
9.9	.895	102	+ 5
10.0	.888	109	+25

Table 3.2

SODIUM BROMIDE SOLUTION REQUIREMENTS **USING SACKED NaBr**

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	Water bbl	95 % NaBr lb	
8.4	.998	2.1	31
8.5	.996	7.6	30
8.6	.992	13.7	29
8.7	.989	19.2	29
8.8	.984	25.0	28
8.9	.979	31.0	26
9.0	.975	36.7	25
9.1	.970	42.6	24
9.2	.966	48.3	23
9.3	.961	54.2	22
9.4	.956	60.2	21
9.5	.950	66.4	20
9.6	.946	72.0	19
9.7	.941	77.9	18
9.8	.937	83.6	16
9.9	.933	89.2	15
10.0	.927	95.4	14
10.1	.923	101.1	12
10.2	.918	107.1	11
10.3	.914	112.6	10
10.4	.910	118.2	8
10.5	.905	124.1	6
10.6	.900	130.2	5
10.7	.895	136.0	4
10.8	.891	141.7	2
10.9	.886	147.6	0
11.0	.882	153.3	- 2

Table 3.2

SODIUM BROMIDE SOLUTION REQUIREMENTS **USING SACKED NaBr**

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	Water bbl	95% NaBr lb	
11.1	.877	159.2	- 3
11.2	.872	165.1	- 5
11.3	.867	171.1	- 7
11.4	.862	177.0	- 9
11.5	.857	183.0	-11
11.6	.853	188.6	-14
11.7	.847	194.8	-16
11.8	.844	200.2	-19
11.9	.839	206.0	-10
12.0	.834	212.0	6
12.1	.831	217.3	14
12.2	.825	223.6	27
12.3	.823	228.5	34
12.4	.816	235.1	43
12.5	.812	240.7	50
12.6	.807	246.7	57
12.7	.804	252.0	63

Table 3.3

POTASSIUM CHLORIDE SOLUTION REQUIREMENTS **USING SACKED KCl (100%)**

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	Water bbl	100% KCl lb	
8.4	.995	4.0	+31
8.5	.986	11.6	29
8.6	.976	18.9	28
8.7	.969	26.1	26
8.8	.960	33.4	25
8.9	.950	40.7	23
9.0	.943	47.9	22
9.1	.933	55.2	20
9.2	.924	62.4	18
9.3	.917	69.7	16
9.4	.907	76.9	14
9.5	.898	84.2	18
9.6	.890	91.5	40
9.7	.881	98.7	60

NOTE:

If the KCl used is less than 100% pure, use the following formula to adjust the starting volume.

$$\text{Starting Vol. (from table)} \times \frac{\text{lb KCl (from Table 3.3)}}{\% \text{ purity of KCl}} + \frac{(100\% \text{ purity of KCl})}{8.33 \times 42} = \text{corrected starting volume}$$

$$\frac{\text{lb KCl (from Table 3.3)}}{\% \text{ of purity of KCl}} = \text{corrected lb KCl}$$

Table 3.4

**POTASSIUM BROMIDE (KBr) 98%
CONCENTRATE + WATER
(CALCULATED)**

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	Water bbl	98% KBr, lb	
8.6	.985	15.1	30
8.7	.980	21.9	30
8.8	.974	28.1	29
8.9	.967	34.8	28
9.0	.962	40.8	27
9.1	.956	47.0	27
9.2	.954	52.6	26
9.3	.947	58.6	26
9.4	.942	64.7	25
9.5	.937	70.6	24
9.6	.932	76.6	23
9.7	.928	82.3	22
9.8	.922	88.5	22
9.9	.916	94.8	21
10.0	.911	100.8	19
10.1	.905	106.9	18
10.2	.901	112.7	17
10.3	.895	119.0	16
10.4	.888	125.4	15
10.5	.883	131.4	14
10.6	.878	137.6	12
10.7	.872	143.8	13
10.8	.865	150.6	20
10.9	.858	157.0	27

Table 3.4

**POTASSIUM BROMIDE (KBr) 98%
CONCENTRATE + WATER
CALCULATED**

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	Water bbl	98% KBr, lb	
11.0	.854	162.6	33
11.1	.847	169.2	41
11.2	.842	175.5	49
11.3	.835	181.8	57
11.4	.829	188.2	66
11.5	.824	194.2	75
11.6	.818	200.0	84
11.7	.812	205.5	93
11.8	.806	210.8	102
11.9	.800	215.8	111
12.0	.794	220.5	120
12.1	.788	225.0	129
12.2	.782	229.2	138
12.3	.776	233.2	147
12.4	.770	237.0	156
12.5	.764	240.5	165
12.6	.758	243.8	174
12.7	.752	246.8	183
12.8	.746	249.5	192
12.9	.740	252.0	201
13.0	.734	254.2	210

Table 3.5

POTASSIUM CHLORIDE / POTASSIUM BROMIDE SOLUTION REQUIREMENTS

USING 9.8 lb/gal KCl AND 10.9 lb/gal KBr

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	9.8 lb/gal KCl, bbl	10.9 lb/gal KBr, bbl	
9.8	1.0000	.0000	70
9.9	.9091	.0909	62
10.0	.8182	.1818	53
10.1	.7273	.2727	45
10.2	.6364	.3636	36
10.3	.5455	.4545	33
10.4	.4545	.5455	27
10.5	.3636	.6364	23
10.6	.2727	.7273	26
10.7	.1818	.8182	28
10.8	.0909	.9091	32
10.9	.0000	1.0000	35

Table 3.6

SODIUM CHLORIDE / SODIUM BROMIDE SOLUTION REQUIREMENTS

USING SACKED NaCl (100%) AND NaBr

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	Water bbl	100 % NaCl lb	95 % NaBr lb	
10.0	.886	110.0	0.0	30
10.1	.883	106.0	9.3	30
10.2	.880	102.0	18.6	30
10.3	.877	97.8	27.9	30
10.4	.874	93.7	37.1	30
10.5	.871	89.6	46.4	30
10.6	.868	85.6	55.7	30
10.7	.865	81.5	65.0	30
10.8	.862	77.4	74.3	30
10.9	.859	73.4	83.6	30
11.0	.856	69.3	92.8	30
11.1	.853	65.2	102.0	30
11.2	.850	61.2	111.0	30
11.3	.847	57.1	121.0	30
11.4	.844	52.9	130.0	30
11.5	.841	48.8	139.0	30
11.6	.838	44.8	149.0	30
11.7	.835	40.7	158.0	30
11.8	.832	36.6	167.0	30
11.9	.829	32.6	177.0	30
12.0	.826	28.5	186.0	37
12.1	.823	24.4	195.0	41
12.2	.820	20.4	204.0	47
12.3	.818	16.3	214.0	49

Table 3.6

SODIUM CHLORIDE / SODIUM BROMIDE SOLUTION REQUIREMENTS

USING SACKED NaCl (100%) AND NaBr

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	Water bbl	100 % NaCl lb	95 % NaBr lb	
12.4	.815	12.2	223.0	53
12.5	.812	8.1	232.0	56
12.6	.809	4.1	242.0	60
12.7	.806	0.0	251.0	63

Table 3.7

SODIUM CHLORIDE / SODIUM BROMIDE SOLUTION REQUIREMENTS

USING 10.0 lb/gal NaCl AND 12.4 lb/gal NaBr

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	10.0 lb/gal NaCl, bbl	12.4 lb/gal NaBr, bbl	
10.0	1.000	.000	30
10.1	.958	.042	30
10.2	.917	.083	30
10.3	.875	.125	30
10.4	.833	.167	30
10.5	.792	.208	30
10.6	.750	.250	30
10.7	.708	.292	30
10.8	.667	.333	30
10.9	.625	.375	30
11.0	.583	.417	30
11.1	.542	.458	30
11.2	.500	.500	30
11.3	.458	.542	30
11.4	.417	.583	30
11.5	.375	.625	30
11.6	.333	.667	30
11.7	.292	.708	30
11.8	.250	.750	30
11.9	.208	.792	23
12.0	.167	.833	28
12.1	.125	.875	32
12.2	.083	.917	36
12.3	.042	.958	39
12.4	.000	1.000	46

Table 3.8

POTASSIUM CHLORIDE / SODIUM CHLORIDE SOLUTION REQUIREMENTS

USING SACKED LOW KCl AND HIGH NaCl

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	Water bbl	KCl lb	NaCl lb	
8.4	.993	1	3	31
8.5	.985	3	6	30
8.6	.978	5	11	27
8.7	.972	7	16	25
8.8	.966	8	20	24
8.9	.962	9	25	22
9.0	.954	10	31	11
9.1	.948	12	36	18
9.2	.939	14	42	15
9.3	.931	16	48	13
9.4	.921	18	54	10
9.5	.913	20	59	7
9.6	.904	22	65	3
9.7	.897	24	69	0
9.8	.888	26	75	-3
9.9	.882	28	81	-7
10.0	.875	30	86	22

Table 3.9

POTASSIUM CHLORIDE / SODIUM CHLORIDE SOLUTION REQUIREMENTS

USING SACKED KCl AND NaCl

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	Water bbl	KCl lb	NaCl lb	
8.4	.993	2	2	32
8.5	.986	5	5	30
8.6	.977	8	9	28
8.7	.971	12	12	26
8.8	.963	15	15	24
8.9	.959	17	19	23
9.0	.952	21	22	21
9.1	.943	25	25	18
9.2	.934	30	30	15
9.3	.928	33	33	13
9.4	.919	37	37	11
9.5	.910	40	41	8
9.6	.901	44	45	5
9.7	.892	47	48	4
9.8	.885	51	52	31
9.9	.878	54	55	39
10.0	.868	58	59	55

Table 3.10

SODIUM CHLORIDE / CALCIUM CHLORIDE SOLUTION REQUIREMENTS

USING SACKED NaCl (100%) AND CaCl₂ (94-97%)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	Water bbl	100% NaCl lb	94-97% CaCl ₂ lb	
10.1	.887	88	29	- 4
10.2	.875	70	52	-10
10.3	.875	54	72	-15
10.4	.876	41	89	-21
10.5	.871	32	104	-26
10.6	.868	25	116	-32
10.7	.866	20	126	-38
10.8	.864	16	135	-42
10.9	.862	13	144	-24
11.0	.859	10	151	-12
11.1	.854	8	159	0

Table 3.11

CALCIUM CHLORIDE SOLUTION REQUIREMENTS **USING CaCl₂ (94-97%)**

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	Water bbl	94-97% CaCl ₂ lb	
8.4	1.000	2.9	31
8.5	.997	8.2	30
8.6	.994	13.4	29
8.7	.991	18.7	27
8.8	.987	24.2	25
8.9	.984	29.4	24
9.0	.980	35.1	22
9.1	.977	40.5	20
9.2	.972	46.2	18
9.3	.968	52.0	15
9.4	.963	57.8	13
9.5	.959	63.4	10
9.6	.954	69.3	7
9.7	.949	75.4	4
9.8	.944	81.5	0
9.9	.939	87.4	- 4
10.0	.934	93.2	- 9
10.1	.929	99.3	-13
10.2	.923	105.4	-18
10.3	.918	111.3	-23
10.4	.912	117.6	-29
10.5	.908	123.5	-36
10.6	.902	129.8	-43
10.7	.895	136.3	-51
10.8	.891	142.0	-57
10.9	.885	148.3	-35
11.0	.878	155.0	-19

Table 3.11

CALCIUM CHLORIDE SOLUTION REQUIREMENTS **USING CaCl_2 (94-97%)**

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	Water bbl	94-97% CaCl_2 lb	
11.1	.872	161.3	- 6
11.2	.866	167.6	7
11.3	.859	174.1	18
11.4	.853	180.4	27
11.5	.846	186.9	36
11.6	.840	193.2	44
11.7	.834	199.5	53
11.8	.828	205.8	62
11.9	.822	212.1	71
12.0	.816	218.4	80
12.1	.810	224.7	89
12.2	.804	231.0	98
12.3	.798	237.3	107
12.4	.792	243.6	116
12.5	.786	249.9	125
12.6	.780	256.2	134
12.7	.774	262.5	143
12.8	.768	268.8	152
12.9	.762	275.1	161
13.0	.756	281.4	170
13.1	.750	287.7	179
13.2	.744	294.0	188
13.3	.738	300.3	197
13.4	.732	306.6	206
13.5	.726	312.9	215
13.6	.720	319.2	224
13.7	.714	325.5	233
13.8	.708	331.8	242
13.9	.702	338.1	251
14.0	.696	344.4	260

SAMPLE CALCULATION FOR PREPARING CaCl_2 BRINE USING TABLE 3.11

Determine material requirements for preparation of 350 bbl of 11.4 lb/gal CaCl_2 .

Water requirement:

$$350 \text{ bbl} \times .853 \text{ bbl/bbl} = 299 \text{ bbl}$$

Dry CaCl_2 requirement:

$$350 \text{ bbl} \times 180.4 \text{ lb/bbl} = 63,140 \text{ lb}$$

(789 80-lb sacks)

DILUTING CaCl_2 BRINE

Diluting a CaCl_2 Brine with fresh water to lower the density.

$$\text{H}_2\text{O} / \text{CaCl}_2 = 42 (\text{Sp. Gr}) \frac{\% \text{CaCl}_2 / - \% \text{CaCl}_2 \text{F}}{\% \text{CaCl}_2 \text{F}}$$

Where

$\text{H}_2\text{O}/\text{CaCl}_2$ = the number of gallons of water per barrel of CaCl_2

Sp.Gr = the specific gravity of the initial brine

$\% \text{CaCl}_2 /$ = the initial percentage of CaCl_2

$\% \text{CaCl}_2 \text{F}$ = the final percentage of CaCl_2

Adding dry CaCl_2 to a CaCl_2 brine to increase density

$$\frac{\text{lb of CaCl}_2}{\text{bbl of CaCl}_2 \text{ brine}} = \frac{42 \times \text{Di} (\% \text{CaCl}_2 \text{F} - \% \text{CaCl}_2 /)}{(\text{CaCl}_2 \% \text{p} - \% \text{CaCl}_2 \text{F})}$$

Where

Di = initial density lb/gal

$\% \text{CaCl}_2 /$ = the initial percentage of CaCl_2

$\% \text{CaCl}_2 \text{F}$ = the final percentage of CaCl_2

$\text{CaCl}_2 \% \text{p}$ = the final percentage of CaCl_2

Note:

Adding water or a dry CaCl_2 to a CaCl_2 brine will cause an increase in volume.

SAMPLE CALCULATION FOR PREPARING CaCl_2 BRINE USING TABLE 3.11

(Continued)

When adding water, the increase in volume will be approximately equal to the amount of water added.

When adding CaCl_2 , the increase in volume may be up to five gallons per barrel going from a 10 lb/gal brine to 11.7 pounds per gallon.

TABLE 3.11 A

Density Versus Percent Composition for Calcium Chloride Brine

Brine Density lb/gal	Percentage of CaCl_2 in solution	Sp.Gr.
10.0	21.5	1.2000
10.1	22.5	1.2125
10.2	23.6	1.2245
10.3	24.6	1.2365
10.4	25.6	1.2485
10.5	26.7	1.2605
10.6	27.7	1.2725
10.7	28.7	1.2845
10.8	29.7	1.2965
10.9	30.7	1.3085
11.0	31.8	1.3205
11.1	32.8	1.3325
11.2	33.9	1.3445
11.3	34.8	1.3565
11.4	35.7	1.3685
11.5	36.6	1.3806
11.6	37.6	1.3926
11.7	38.5	1.4046

Sample Calculations Using Table 3.11 A

1. What volume of water would be required to drop the density of 200 barrels of 11.5 lb/gal CaCl_2 brine to 10.5 lb/gal?

$$\text{gallons H}_2\text{O/bbl} = 42 \times \frac{1.3806 \times (36.6 - 26.7)}{26.7} = 21.5 \text{ gal/bbl}$$

$$\begin{aligned} 21.5 \text{ gal} \times 200 &= 4300 \text{ gal} \\ 4300 \text{ gal} / 42 &= 102 \text{ bbl H}_2\text{O} \\ \text{Volume Inc.} &= 102 \text{ bbl} \end{aligned}$$

2. What weight of CaCl_2 (95% pure) would be required to raise the density of 200 barrels of 10.5 lb.gal CaCl_2 brine to 11.5 lb/gal?

$$\begin{aligned} \text{lb CaCl}_2 \text{ (95\% pure)} / \text{bbl} &= 42 \times \frac{10.5 \times (36.6 - 26)}{(95 - 36.6)} \\ &= 74.8 \text{ lb/bbl multiply by 200} \\ &= 14960 \text{ lb CaCl}_2 \text{ (95\% pure)} \end{aligned}$$

$$\text{volume increase} = \frac{11.5 - 10.5}{11.7 - 10.0} \times 5 \times 200 = 588 \text{ gal (14 bbl)}$$

Table 3.12

CALCIUM BROMIDE SOLUTION REQUIREMENTS **USING CaBr₂ (91.5%)**

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	Water bbl	91.5% CaBr ₂ lb	
11.0	.8562	162.52	- 2
11.1	.8552	167.07	- 4
11.2	.8496	173.23	- 6
11.3	.8423	179.99	- 9
11.4	.8347	186.85	-11
11.5	.8299	192.71	-14
11.6	.8264	198.17	-16
11.7	.8180	205.28	-19
11.8	.8142	210.84	-23
11.9	.8069	217.58	-25
12.0	.7995	224.39	-28
12.1	.7949	230.18	-30
12.2	.7886	236.59	-34
12.3	.7854	241.93	-36
12.4	.7770	249.05	-40
12.5	.7685	256.25	-44
12.6	.7646	261.79	-47
12.7	.7573	268.56	-52
12.8	.7514	274.82	-55
12.9	.7417	281.73	-61
13.0	.7375	288.11	-63
13.1	.7345	293.35	-66
13.2	.7244	301.07	-71
13.3	.7194	307.04	-76
13.4	.7124	313.68	-79
13.5	.7053	320.38	-81
13.6	.6997	326.52	-81

Table 3.12

CALCIUM BROMIDE SOLUTION REQUIREMENTS **USING CaBr_2 (91.5%)**

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	Water bbl	91.5% CaBr_2 lb	
13.7	.6904	333.99	-81
13.8	.6827	340.89	-81
13.9	.6767	347.20	-80
14.0	.6668	354.87	-50
14.1	.6603	361.32	-40
14.2	.6538	367.80	-20
14.3	.6471	374.36	10
14.4	.6364	382.30	23
14.5	.6255	390.31	35

Table 3.13

CALCIUM BROMIDE SOLUTION REQUIREMENTS
USING 14.2 lb/gal CaBr_2 AND SACKED CaBr_2

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	14.2 lb/gal CaBr_2 bbl	95 % CaBr_2 lb	
14.3	.990	10.4	25
14.4	.980	20.6	32
14.5	.973	28.9	37
14.6	.963	38.8	43
14.7	.955	47.7	49
14.8	.948	56.4	55
14.9	.939	65.7	60
15.0	.933	73.5	65
15.1	.926	81.9	71
15.2	.919	90.1	76
15.3	.910	99.6	81
15.4	.906	106.3	37

Table 3.14

CALCIUM BROMIDE SOLUTION REQUIREMENTS
USING 14.2 lb/gal CaBr₂ AND SACKED CaBr₂

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	14.2 lb/gal CaBr ₂ bbl	95% CaBr ₂ lb	
14.2	1.0000		15
14.3	.9909	9.60	21
14.4	.9822	19.04	25
14.5	.9736	28.34	30
14.6	.9654	37.43	35
14.7	.9574	46.39	41
14.8	.9497	55.22	46
14.9	.9421	63.91	52
15.0	.9348	72.48	56
15.1	.9277	80.92	64
15.2	.9208	89.24	70
15.3	.9143	97.47	76
15.4	.9075	105.54	79
15.5	.9012	113.64	81
15.6	.8952	121.68	84
15.7	.8895	129.68	88
15.8	.8841	137.64	92
15.9	.8789	145.56	96
16.0	.8740	153.44	100
16.1	.8693	161.28	104
16.2	.8648	169.08	108
16.3	.8605	176.84	112
16.4	.8564	184.56	116
16.5	.8524	192.24	120
16.6	.8486	199.88	124
16.7	.8449	207.48	128
16.8	.8414	215.04	132
16.9	.8380	222.56	136
17.0	.8348	230.04	140
17.1	.8317	237.48	144
17.2	.8287	244.88	148
17.3	.8258	252.24	152
17.4	.8230	259.56	156
17.5	.8203	266.84	160
17.6	.8177	274.08	164
17.7	.8152	281.28	168
17.8	.8127	288.44	172
17.9	.8103	295.56	176
18.0	.8080	302.64	180
18.1	.8057	309.68	184
18.2	.8035	316.68	188
18.3	.8013	323.64	192
18.4	.7992	330.56	196
18.5	.7971	337.44	200
18.6	.7951	344.28	204
18.7	.7931	351.08	208
18.8	.7912	357.84	212
18.9	.7893	364.56	216
19.0	.7875	371.24	220
19.1	.7857	377.88	224
19.2	.7839	384.48	228
19.3	.7822	391.04	232
19.4	.7805	397.56	236
19.5	.7788	404.04	240
19.6	.7772	410.48	244
19.7	.7756	416.88	248
19.8	.7740	423.24	252
19.9	.7725	429.56	256
20.0	.7710	435.84	260

Table 3.15

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING SACKED CaCl_2 (94-97%) AND CaBr_2 (91.5%)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	Water bbl	94-97% CaCl_2 lb	91.5% CaBr_2 lb	
11.7	.8490	195.4	6.24	45
11.8	.8420	193.1	15.00	51
11.9	.8350	190.8	23.70	52
12.0	.8280	188.5	32.40	54
12.1	.8200	186.1	41.10	55
12.2	.8130	183.9	49.80	55
12.3	.8060	181.6	58.60	56
12.4	.7990	179.3	67.30	56
12.5	.7920	177.0	76.00	57
12.6	.7845	174.7	84.70	57
12.7	.7770	172.4	93.40	58
12.8	.7700	170.1	102.20	58
12.9	.7630	167.8	110.90	59
13.0	.7560	165.5	119.60	59
13.1	.7485	163.2	128.30	60
13.2	.7415	160.9	137.00	60
13.3	.7340	158.6	145.80	60
13.4	.7270	156.3	154.50	61
13.5	.7200	154.0	163.20	61
13.6	.7130	151.7	171.90	62
13.7	.7055	149.4	180.60	62
13.8	.6980	147.1	189.40	63
13.9	.6910	144.8	198.10	63
14.0	.6840	142.5	206.80	64

Table 3.15

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING SACKED CaCl_2 (94-97%) AND CaBr_2 (91.5%)

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	Water bbl	94-97% CaCl_2 lb	91.5% CaBr_2 lb	
14.1	.6770	140.2	215.50	64
14.2	.6695	137.9	224.25	64
14.3	.6620	135.6	233.00	65
14.4	.6550	133.3	241.70	65
14.5	.6480	131.0	250.40	65
14.6	.6410	128.7	259.10	66
14.7	.6335	126.4	267.85	66
14.8	.6260	124.1	276.60	67
14.9	.6190	121.8	285.30	67
15.0	.6120	119.5	294.00	67
15.1	.6050	117.2	302.70	68

Table 3.16

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.6 lb/gal CaCl_2 , 14.2 lb/gal CaBr_2 , AND
SACKED CaCl_2 (80%)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	11.6 lb/gal CaCl_2 bbl	14.2 lb/gal CaBr_2 bbl	80% CaCl_2 lb	
11.7	.9693	.0254	3.87	45
11.8	.9385	.0507	8.20	51
11.9	.9077	.0762	12.30	52
12.0	.8769	.1016	16.41	54
12.1	.8462	.1269	20.50	55
12.2	.8154	.1524	24.60	55
12.3	.7846	.1778	28.71	56
12.4	.7539	.2032	32.80	56
12.5	.7231	.2286	36.91	57
12.6	.6923	.2540	41.01	57
12.7	.6616	.2794	45.11	58
12.8	.6309	.3048	49.21	58
12.9	.6001	.3302	53.32	59
13.0	.5693	.3556	57.42	59
13.1	.5385	.3810	61.52	60
13.2	.5078	.4064	65.60	60
13.3	.4770	.4318	69.72	60
13.4	.4462	.4572	73.82	61
13.5	.4155	.4826	77.92	61
13.6	.3847	.5080	82.02	62
13.7	.3539	.5334	86.13	62
13.8	.3231	.5589	90.23	63
13.9	.2924	.5842	94.33	63
14.0	.2616	.6069	98.43	64

Table 3.16

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

**USING 11.6 lb/gal CaCl_2 , 14.2 lb/gal CaBr_2 , AND
SACKED CaCl_2 (80%)**

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	11.6 lb/gal CaCl_2 bbl	14.2 lb/gal CaBr_2 bbl	80% CaCl_2 lb	
14.1	.2308	.6351	102.53	64
14.2	.2001	.6604	106.63	64
14.3	.1693	.6858	110.72	65
14.4	.1385	.7113	114.84	65
14.5	.1078	.7366	118.92	65
14.6	.0770	.7620	123.04	66
14.7	.0462	.7875	127.14	66
14.8	.0155	.8128	131.22	67
14.9	.0000	.8382	135.33	67

Table 3.17

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.6 lb/gal CaCl_2 , 14.2 lb/gal CaBr_2 ,
SACKED CaCl_2 (94-97%) AND CaBr_2 (91.5%)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)				Crystallization Point (LCTD), °F
	11.6 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	CaCl_2 (94-97%) lb	CaBr_2 (91.5%) lb	
11.8	.9672	.0157	14.97	----	--
11.9	.9450	.0404	20.19	----	59
12.0	.8739	.1099	12.72	----	--
12.1	.8439	.1381	14.70	----	--
12.2	.8132	.1668	16.71	----	--
12.3	.7821	.1959	18.69	----	--
12.4	.7503	.2255	20.76	----	--
12.5	.7183	.2555	22.68	----	59
12.6	.6852	.2876	23.88	----	--
12.7	.6581	.3116	26.91	----	--
12.8	.6273	.3403	29.04	----	--
12.9	.5959	.3694	31.20	----	--
13.0	.5639	.3988	33.42	----	59
13.1	.5291	.4285	36.87	----	--
13.2	.5084	.4475	39.81	----	--
13.3	.4706	.4879	38.37	----	--
13.4	.4389	.5179	40.11	----	--
13.5	.4075	.5473	42.06	----	55
13.6	.3710	.5770	46.32	----	--
13.7	.3385	.6063	48.87	----	--
13.8	.3055	.6360	51.42	----	--
13.9	.2720	.6661	54.03	----	--
14.0	.2413	.6967	54.93	----	55
14.1	.2092	.7277	56.28	----	--

Table 3.17

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

**USING 11.6 lb/gal CaCl_2 , 14.2 lb/gal CaBr_2 ,
SACKED CaCl_2 (94-97%) AND CaBr_2 (91.5%)**

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)				Crystallization Point (LCTD), °F
	11.6 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	CaCl_2 (94-97%) lb	CaBr_2 (91.5%) lb	
14.2	.1773	.7586	57.54	----	--
14.3	.1447	.7901	58.86	----	59
14.4	.1116	.8220	60.18	----	--
14.5	.0779	.8543	61.56	----	55
14.6	.0000	.9478	47.94	----	--
14.7	.0000	.9374	43.32	15.0	--
14.8	.0000	.9431	15.06	44.4	--
14.9	.0000	1.0060	0.00	64.5	--

Table 3.18

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

**USING 11.6 lb/gal CaCl_2 , 14.2 lb/gal CaBr_2 ,
SACKED CaCl_2 (94-97%) AND CaBr_2 (91.5%)**

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)				Crystallization Point (LCTD), °F
	11.6 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	CaCl_2 (94-97%) lb	CaBr_2 (91.5%) lb	
11.9	.8768	.1205	0.74	----	52
12.0	.8645	.1280	6.49	----	--
12.1	.8137	.1756	7.05	----	--
12.2	.7840	.2033	9.19	----	--
12.3	.7587	.2280	10.97	----	--
12.4	.7182	.2684	10.82	----	--
12.5	.7073	.2806	13.04	----	49
12.6	.6777	.3081	15.28	----	--
12.7	.6409	.3326	22.77	----	--
12.8	.6048	.3729	20.54	----	--
12.9	.5803	.3994	20.89	----	--
13.0	.5607	.4171	24.07	----	50
13.1	.5096	.4615	26.70	----	--
13.2	.4735	.4967	27.48	----	--
13.3	.4422	.5267	28.91	----	--
13.4	.4154	.5526	30.84	----	--
13.5	.3932	.5764	31.70	----	46
13.6	.3437	.6206	33.61	----	--
13.7	.3186	.6426	36.94	----	--
13.8	.2860	.6768	36.63	----	--
13.9	.2518	.7086	38.49	----	--
14.0	.2162	.7409	40.80	----	46
14.1	.1744	.7846	39.32	----	--
14.2	.1186	.8338	41.37	----	--

Table 3.19

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

**USING 11.0 lb/gal CaCl_2 , 14.2 lb/gal CaBr_2 , AND
SACKED CaCl_2 (94-97%)**

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	11.0 lb/gal CaCl_2 bbl	14.2 lb/gal CaBr_2 bbl	CaCl_2 (94-97%) lb	
11.7	.8293	.1518	18.11	--
11.8	.8049	.1735	20.70	--
11.9	.7805	.1952	23.29	--
12.0	.7561	.2169	25.88	39
12.1	.7317	.2385	28.47	--
12.2	.7073	.2602	31.06	--
12.3	.6829	.2819	33.64	--
12.4	.6585	.3036	36.23	--
12.5	.6341	.3253	38.82	48
12.6	.6098	.3469	41.40	--
12.7	.5854	.3686	43.99	--
12.8	.5610	.3903	46.58	--
12.9	.5366	.4120	49.17	--
13.0	.5122	.4337	51.76	57
13.1	.4878	.4554	54.34	--
13.2	.4634	.4771	56.93	--
13.3	.4390	.4988	59.52	--
13.4	.4146	.5205	62.11	--
13.5	.3902	.5422	64.70	61
13.6	.3659	.5638	67.28	--
13.7	.3415	.5855	69.87	--
13.8	.3171	.6072	72.46	--
13.9	.2927	.6289	75.04	--
14.0	.2683	.6506	77.63	64

Table 3.19

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

**USING 11.0 lb/gal CaCl₂, 14.2 lb/gal CaBr₂, AND
SACKED CaCl₂ (94-97%)**

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	11.0lb/gal CaCl ₂ bbl	14.2lb/gal CaBr ₂ bbl	CaCl ₂ (94-97%) lb	
14.1	.2439	.6722	80.22	--
14.2	.2195	.6939	82.81	--
14.3	.1951	.7156	85.40	--
14.4	.1707	.7373	87.99	--
14.5	.1463	.7590	90.58	64
14.6	.1220	.7806	93.16	--
14.7	.0976	.8023	95.74	--
14.8	.0732	.8240	98.33	--
14.9	.0488	.8457	100.92	--
15.0	.0244	.8674	103.51	--
15.1	.0000	.8891	106.10	--

Table 3.20

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

**USING 11.0 lb/gal CaCl_2 , 14.2 lb/gal CaBr_2 , AND
SACKED CaCl_2 (94-97%)**

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	11.0lb/gal CaCl_2 bbl	14.2lb/gal CaBr_2 bbl	CaCl_2 (94-97%) lb	
11.7	.8446	.1379	18.58	--
11.8	.8108	.1724	17.84	--
11.9	.7770	.2069	17.09	--
12.0	.7432	.2414	16.35	39
12.1	.7094	.2759	15.61	--
12.2	.6757	.3103	14.87	--
12.3	.6419	.3448	14.12	--
12.4	.6081	.3793	13.38	--
12.5	.5743	.4138	12.63	12
12.6	.5405	.4483	11.89	--
12.7	.5067	.4828	11.15	--
12.8	.4730	.5172	10.41	--
12.9	.4392	.5517	9.66	--
13.0	.4054	.5862	8.92	0
13.1	.3716	.6207	8.18	--
13.2	.3378	.6552	7.59	--
13.3	.3040	.6897	6.69	--
13.4	.2703	.7241	5.95	--
13.5	.2365	.7586	5.31	-15
13.6	.2027	.7931	4.46	--
13.7	.1689	.8276	3.72	--
13.8	.1351	.8621	2.97	--
13.9	.1013	.8966	2.23	--
14.0	.0676	.9310	1.49	1
14.1	.0338	.9655	0.74	--
14.2	.0000	1.0000	0.00	15

Table 3.21

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.0 lb/gal CaCl_2 , 14.2 lb/gal CaBr_2 ,
SACKED CaCl_2 (94-97%) AND CaBr_2 (91.5%)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)				Crystallization Point (LCTD), °F
	11.0 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	CaCl_2 (94-97%) lb	CaBr_2 (91.5%) lb	
11.6	.9456	.0320	31.23	----	--
11.7	.8922	.0726	35.92	----	--
11.8	.8514	.1138	34.38	----	--
11.9	.8131	.1558	31.24	----	--
12.0	.7708	.2001	28.53	----	36
12.1	.7500	.2218	29.43	----	--
12.2	.7304	.2421	30.56	----	--
12.3	.7031	.2675	32.25	----	--
12.4	.6751	.2932	34.03	----	--
12.5	.6461	.3196	35.91	----	39
12.6	.6165	.3497	35.82	----	--
12.7	.5862	.3803	35.74	----	--
12.8	.5555	.4114	35.63	----	--
12.9	.5242	.4428	35.53	----	--
13.0	.4923	.4748	35.43	----	37
13.1	.4603	.5069	35.18	----	--
13.2	.4279	.5396	34.92	----	--
13.3	.3949	.5726	34.66	----	--
13.4	.3614	.6061	34.38	----	--
13.5	.3273	.6400	34.08	----	33
13.6	.2934	.6740	33.69	----	--
13.7	.2590	.7084	33.27	----	--
13.8	.2231	.7451	32.14	----	--
13.9	.1865	.7823	31.07	----	--

Table 3.21

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.0 lb/gal CaCl_2 , 14.2 lb/gal CaBr_2 ,
SACKED CaCl_2 (94-97%) AND CaBr_2 (91.5%)

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)				Crystallization Point (LCTD), °F
	11.0 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	CaCl_2 (94-97%) lb	CaBr_2 (91.5%) lb	
14.0	.1494	.8200	29.97	----	30
14.1	.0979	.8705	27.76	----	--
14.2	.0479	.9217	24.57	----	--
14.3	.0257	.9578	17.49	----	--
14.4	----	.9803	10.83	9.30	--
14.5	----	.9972	-----	26.22	--
14.6	----	1.0000	-----	30.00	--
14.7	----	1.0000	-----	30.00	--
14.8	----	1.0000	-----	30.00	--
14.9	----	1.0000	-----	30.00	--
15.0	----	1.0000	-----	30.00	--
15.1	----	1.0000	-----	30.00	--
15.2	----	1.0000	-----	30.00	--
15.3	----	1.0000	-----	30.00	--
15.4	----	1.0000	-----	30.00	--
15.5	----	1.0000	-----	30.00	--
15.6	----	1.0000	-----	30.00	--
15.7	----	1.0000	-----	30.00	--
15.8	----	1.0000	-----	30.00	--
15.9	----	1.0000	-----	30.00	--
16.0	----	1.0000	-----	30.00	--
16.1	----	1.0000	-----	30.00	--
16.2	----	1.0000	-----	30.00	--
16.3	----	1.0000	-----	30.00	--
16.4	----	1.0000	-----	30.00	--
16.5	----	1.0000	-----	30.00	--
16.6	----	1.0000	-----	30.00	--
16.7	----	1.0000	-----	30.00	--
16.8	----	1.0000	-----	30.00	--
16.9	----	1.0000	-----	30.00	--
17.0	----	1.0000	-----	30.00	--
17.1	----	1.0000	-----	30.00	--
17.2	----	1.0000	-----	30.00	--
17.3	----	1.0000	-----	30.00	--
17.4	----	1.0000	-----	30.00	--
17.5	----	1.0000	-----	30.00	--
17.6	----	1.0000	-----	30.00	--
17.7	----	1.0000	-----	30.00	--
17.8	----	1.0000	-----	30.00	--
17.9	----	1.0000	-----	30.00	--
18.0	----	1.0000	-----	30.00	--
18.1	----	1.0000	-----	30.00	--
18.2	----	1.0000	-----	30.00	--
18.3	----	1.0000	-----	30.00	--
18.4	----	1.0000	-----	30.00	--
18.5	----	1.0000	-----	30.00	--
18.6	----	1.0000	-----	30.00	--
18.7	----	1.0000	-----	30.00	--
18.8	----	1.0000	-----	30.00	--
18.9	----	1.0000	-----	30.00	--
19.0	----	1.0000	-----	30.00	--
19.1	----	1.0000	-----	30.00	--
19.2	----	1.0000	-----	30.00	--
19.3	----	1.0000	-----	30.00	--
19.4	----	1.0000	-----	30.00	--
19.5	----	1.0000	-----	30.00	--
19.6	----	1.0000	-----	30.00	--
19.7	----	1.0000	-----	30.00	--
19.8	----	1.0000	-----	30.00	--
19.9	----	1.0000	-----	30.00	--
20.0	----	1.0000	-----	30.00	--

Table 3.22

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

**USING 11.0 lb/gal CaCl₂, 14.2 lb/gal CaBr₂, SACKED CaCl₂ (94-97%)
AND CaBr₂ (91.0%)**

CRYSTALLIZATION POINTS 10° + / -5°F (FCTA)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			
	11.0 lb/gal CaCl ₂ bbl	14.2 lb/gal Ca ₂ bbl	CaCl ₂ (94-97%) lb	CaBr ₂ (91.0%) lb
11.8	.8394	.1312	29.55	27.95
11.9	.8041	.1670	28.74	27.90
12.0	.7683	.2032	27.87	29.02
12.1	.7397	.2299	29.31	28.92
12.2	.7125	.2578	29.49	29.43
12.3	.6847	.2860	29.70	29.94
12.4	.6564	.3147	29.88	30.45
12.5	.6278	.3434	30.15	30.96
12.6	.5988	.3724	30.45	31.47
12.7	.5707	.3999	31.26	31.98
12.8	.5412	.4268	33.03	31.86
12.9	.5114	.4579	32.46	33.00
13.0	.4796	.4878	33.48	33.48
13.1	.4221	.5535	25.08	30.96
13.2	.3914	.5856	24.33	28.44
13.3	.3582	.6156	25.92	29.88
13.4	.3436	.6350	25.35	28.68
13.5	.3233	.6509	29.43	24.81
13.6	.2803	.6975	25.71	24.27
13.7	.2440	.7360	23.73	25.08
13.8	.2071	.7749	21.78	23.88

Table 3.22

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

**USING 11.0 lb/gal CaCl₂, 14.2 lb/gal CaBr₂, SACKED CaCl₂ (94-97%)
AND CaBr₂ (91.0%)**

CRYSTALLIZATION POINTS 10° + / -5°F (FCTA)

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			
	11.0 lb/gal CaCl ₂ bbl	14.2 lb/gal Ca ₂ bbl	CaCl ₂ (94-97%) lb	CaBr ₂ (91.0%) lb
13.9	.1697	.8143	19.74	21.32
14.0	.1314	.8542	17.85	20.86
14.1	.0974	.8792	22.86	20.28
14.2	.0642	.9169	19.92	19.08
14.3	.0290	.9547	17.82	17.82
14.4	.0000	.9799	-----	20.40

Table 3.23

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 10.7 lb/gal CaCl_2 AND 14.2 lb/gal $\text{CaBr}_2/\text{CaCl}_2$

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	10.7 lb/gal CaCl_2 , bbl	14.2 lb/gal $\text{CaBr}_2/\text{CaCl}_2$, bbl	
10.7	1.000	.000	-54
10.8	.971	.029	-57
10.9	.943	.057	-62
11.0	.914	.086	-68
11.1	.886	.114	-59
11.2	.857	.143	-51
11.3	.829	.171	-40
11.4	.800	.200	-31
11.5	.771	.229	-24
11.6	.743	.257	-19
11.7	.714	.286	-15
11.8	.686	.314	- 9
11.9	.657	.343	- 5
12.0	.629	.371	0
12.1	.600	.400	4
12.2	.571	.429	9
12.3	.543	.457	13
12.4	.514	.486	17
12.5	.486	.514	20
12.6	.457	.543	25
12.7	.429	.571	29
12.8	.400	.600	33
12.9	.371	.629	35
13.0	.343	.657	36

Table 3.23

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 10.7 lb/gal CaCl_2 AND 14.2 lb/gal $\text{CaBr}_2/\text{CaCl}_2$

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	10.7 lb/gal CaCl_2 , bbl	14.2 lb/gal $\text{CaBr}_2/\text{CaCl}_2$, bbl	
13.1	.314	.686	38
13.2	.286	.714	40
13.3	.257	.743	43
13.4	.229	.771	44
13.5	.200	.800	46
13.6	.171	.829	49
13.7	.143	.857	52
13.8	.114	.886	55
13.9	.086	.914	57
14.0	.057	.943	60
14.1	.029	.971	62
14.2	.000	1.000	64
13.1	.314	.686	38
13.2	.286	.714	40
13.3	.257	.743	43
13.4	.229	.771	44
13.5	.200	.800	46
13.6	.171	.829	49
13.7	.143	.857	52
13.8	.114	.886	55
13.9	.086	.914	57
14.0	.057	.943	60
14.1	.029	.971	62
14.2	.000	1.000	64
13.1	.314	.686	38
13.2	.286	.714	40
13.3	.257	.743	43
13.4	.229	.771	44
13.5	.200	.800	46
13.6	.171	.829	49
13.7	.143	.857	52
13.8	.114	.886	55
13.9	.086	.914	57
14.0	.057	.943	60
14.1	.029	.971	62
14.2	.000	1.000	64

Table 3.24

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 10.9 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	10.9 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
10.9	1.000	.000	-30
11.0	.970	.030	-18
11.1	.939	.061	-12
11.2	.909	.091	-11
11.3	.879	.121	-11
11.4	.849	.151	-11
11.5	.818	.182	-11
11.6	.788	.212	-11
11.7	.758	.242	-12
11.8	.727	.273	-12
11.9	.697	.303	-12
12.0	.666	.333	-12
12.1	.636	.364	-12
12.2	.606	.394	-12
12.3	.576	.424	-12
12.4	.546	.454	-13
12.5	.515	.485	-13
12.6	.485	.515	-14
12.7	.455	.545	-15
12.8	.424	.576	-16
12.9	.394	.606	-17
13.0	.364	.636	-18
13.1	.333	.667	-19
13.2	.303	.697	-22

Table 3.24

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 10.9 lb/gal CaCl₂ AND 14.2 lb/gal CaBr₂

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	10.9 lb/gal CaCl ₂ , bbl	14.2 lb/gal CaBr ₂ , bbl	
13.3	.273	.727	-20
13.4	.243	.757	-19
13.5	.212	.788	-18
13.6	.182	.818	-17
13.7	.152	.848	-15
13.8	.121	.879	-12
13.9	.091	.909	- 9
14.0	.061	.939	- 3
14.1	.030	.970	- 2
14.2	.000	1.000	15
14.3			
14.4			
14.5			
14.6			
14.7			
14.8			
14.9			
15.0			
15.1			
15.2			
15.3			
15.4			
15.5			
15.6			
15.7			
15.8			
15.9			
16.0			
16.1			
16.2			

Table 3.25

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.0 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.0 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
11.0	1.000	.000	-17
11.1	.969	.031	-11
11.2	.938	.062	- 5
11.3	.906	.093	- 1
11.4	.875	.125	1
11.5	.844	.156	1
11.6	.813	.187	1
11.7	.781	.219	0
11.8	.750	.250	0
11.9	.719	.281	- 1
12.0	.687	.313	- 2
12.1	.656	.344	- 3
12.2	.625	.375	- 3
12.3	.594	.406	- 4
12.4	.562	.438	- 6
12.5	.531	.469	- 8
12.6	.500	.500	-10
12.7	.469	.531	-12
12.8	.437	.563	-13
12.9	.406	.594	-15
13.0	.375	.625	-16
13.1	.344	.656	-17
13.2	.312	.688	-18
13.3	.281	.719	-18

Table 3.25

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.0 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.0 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
13.4	.250	.750	-17
13.5	.219	.781	-16
13.6	.187	.813	-14
13.7	.156	.844	-12
13.8	.125	.875	-10
13.9	.093	.906	- 7
14.0	.062	.938	- 5
14.1	.031	.969	- 2
14.2	.000	1.000	15

Table 3.26

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.1 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.1 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
11.1	1.000	.000	- 8
11.2	.968	.032	- 5
11.3	.935	.065	- 4
11.4	.903	.097	- 2
11.5	.871	.129	1
11.6	.839	.161	0
11.7	.806	.194	1
11.8	.774	.226	2
11.9	.742	.258	2
12.0	.710	.290	3
12.1	.677	.323	3
12.2	.645	.355	3
12.3	.613	.387	2
12.4	.581	.419	2
12.5	.548	.452	0
12.6	.516	.484	- 2
12.7	.484	.516	- 5
12.8	.452	.548	- 7
12.9	.419	.581	- 8
13.0	.387	.613	- 9
13.1	.355	.645	-11
13.2	.323	.677	-12
13.3	.290	.710	-14
13.4	.258	.742	-15

Table 3.26

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.1 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.1 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
13.5	.226	.774	-15
13.6	.194	.806	-13
13.7	.161	.839	-11
13.8	.129	.871	- 8
13.9	.097	.903	- 5
14.0	.065	.935	- 2
14.1	.032	.968	0
14.2	.000	1.000	15
13.1	.000	.000	1.00
13.2	.000	.000	2.00
13.3	.000	.000	3.00
13.4	.000	.000	4.00
13.5	.000	.000	5.00
13.6	.000	.000	6.00
13.7	.000	.000	7.00
13.8	.000	.000	8.00
13.9	.000	.000	9.00
14.0	.000	.000	10.00
14.1	.000	.000	11.00
14.2	.000	.000	12.00
14.3	.000	.000	13.00
14.4	.000	.000	14.00
14.5	.000	.000	15.00
14.6	.000	.000	16.00
14.7	.000	.000	17.00
14.8	.000	.000	18.00
14.9	.000	.000	19.00
15.0	.000	.000	20.00

Table 3.27

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.2 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.2 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
11.2	1.000	.000	6
11.3	.967	.033	7
11.4	.933	.067	8
11.5	.900	.100	9
11.6	.867	.123	9
11.7	.833	.167	10
11.8	.800	.200	11
11.9	.767	.233	11
12.0	.733	.267	12
12.1	.700	.300	12
12.2	.667	.333	12
12.3	.633	.367	10
12.4	.600	.400	8
12.5	.567	.433	7
12.6	.533	.467	5
12.7	.500	.500	3
12.8	.467	.533	1
12.9	.433	.567	- 1
13.0	.400	.600	- 3
13.1	.367	.633	- 6
13.2	.333	.667	- 8
13.3	.300	.700	-10
13.4	.267	.733	-10
13.5	.233	.767	-11

Table 3.27

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.2 lb/gal CaCl₂ AND 14.2 lb/gal CaBr₂

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.2 lb/gal CaCl ₂ , bbl	14.2 lb/gal CaBr ₂ , bbl	
13.6	.200	.800	-11
13.7	.167	.833	-10
13.8	.133	.867	- 8
13.9	.100	.900	- 6
14.0	.067	.933	- 3
14.1	.033	.967	2
14.2	.000	1.000	15
14.3			
14.4			
14.5			
14.6			
14.7			
14.8			
14.9			
15.0			
15.1			
15.2			
15.3			
15.4			
15.5			
15.6			
15.7			
15.8			
15.9			
16.0			
16.1			
16.2			
16.3			
16.4			
16.5			
16.6			
16.7			
16.8			
16.9			
17.0			
17.1			
17.2			
17.3			
17.4			
17.5			
17.6			
17.7			
17.8			
17.9			
18.0			
18.1			
18.2			
18.3			
18.4			
18.5			
18.6			
18.7			
18.8			
18.9			
19.0			
19.1			
19.2			
19.3			
19.4			
19.5			
19.6			
19.7			
19.8			
19.9			
20.0			

Table 3.28

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.3 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.3 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
11.3	1.000	.000	20
11.4	.965	.034	19
11.5	.932	.068	17
11.6	.897	.103	17
11.7	.863	.137	15
11.8	.828	.172	13
11.9	.794	.206	13
12.0	.759	.241	12
12.1	.724	.276	11
12.2	.690	.310	11
12.3	.655	.345	10
12.4	.621	.379	10
12.5	.586	.414	10
12.6	.552	.448	9
12.7	.517	.483	8
12.8	.483	.517	8
12.9	.448	.552	7
13.0	.414	.586	7
13.1	.379	.621	7
13.2	.345	.655	5
13.3	.310	.690	3
13.4	.276	.724	- 1
13.5	.241	.759	- 2
13.6	.207	.793	- 2

Table 3.28

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.3 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.3 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
13.7	.173	.827	0
13.8	.138	.862	2
13.9	.104	.896	4
14.0	.069	.931	6
14.1	.035	.965	10
14.2	.000	1.000	15
13.6	.208	.792	-2
13.5	.243	.757	-4
13.4	.278	.722	-6
13.3	.313	.687	-8
13.2	.348	.652	-10
13.1	.383	.617	-12
13.0	.418	.582	-14
12.9	.453	.547	-16
12.8	.488	.512	-18
12.7	.523	.477	-20
12.6	.558	.442	-22
12.5	.593	.407	-24
12.4	.628	.372	-26
12.3	.663	.337	-28
12.2	.698	.302	-30
12.1	.733	.267	-32
12.0	.768	.232	-34
11.9	.803	.197	-36
11.8	.838	.162	-38
11.7	.873	.127	-40
11.6	.908	.092	-42
11.5	.943	.057	-44
11.4	.978	.022	-46
11.3	1.013	-.013	-48
11.2	1.048	-.048	-50
11.1	1.083	-.083	-52
11.0	1.118	-.118	-54
10.9	1.153	-.153	-56
10.8	1.188	-.188	-58
10.7	1.223	-.223	-60
10.6	1.258	-.258	-62
10.5	1.293	-.293	-64
10.4	1.328	-.328	-66
10.3	1.363	-.363	-68
10.2	1.398	-.398	-70
10.1	1.433	-.433	-72
10.0	1.468	-.468	-74
9.9	1.503	-.503	-76
9.8	1.538	-.538	-78
9.7	1.573	-.573	-80
9.6	1.608	-.608	-82
9.5	1.643	-.643	-84
9.4	1.678	-.678	-86
9.3	1.713	-.713	-88
9.2	1.748	-.748	-90
9.1	1.783	-.783	-92
9.0	1.818	-.818	-94
8.9	1.853	-.853	-96
8.8	1.888	-.888	-98
8.7	1.923	-.923	-100

Table 3.29

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.4 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.4 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
11.4	1.000	.000	32
11.5	.964	.036	31
11.6	.929	.071	30
11.7	.893	.107	30
11.8	.857	.143	29
11.9	.821	.179	28
12.0	.786	.214	27
12.1	.750	.250	26
12.2	.714	.286	25
12.3	.679	.321	23
12.4	.643	.357	22
12.5	.607	.393	21
12.6	.571	.429	19
12.7	.536	.464	17
12.8	.500	.500	16
12.9	.464	.536	14
13.0	.429	.571	12
13.1	.393	.607	9
13.2	.357	.643	6
13.3	.321	.679	3
13.4	.286	.714	1
13.5	.250	.750	0
13.6	.214	.786	- 3
13.7	.179	.821	- 5

Table 3.29

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.4 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.4 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
13.8	.143	.857	1
13.9	.107	.893	4
14.0	.071	.929	7
14.1	.036	.964	10
14.2	.000	1.000	15

Table 3.30

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.5 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.5 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
11.5	1.000	.000	41
11.6	.963	.037	40
11.7	.926	.074	40
11.8	.889	.111	39
11.9	.852	.148	38
12.0	.815	.185	37
12.1	.778	.222	36
12.2	.741	.259	34
12.3	.704	.296	32
12.4	.667	.333	30
12.5	.630	.370	29
12.6	.593	.407	28
12.7	.556	.444	26
12.8	.519	.481	24
12.9	.481	.519	21
13.0	.444	.556	19
13.1	.407	.593	18
13.2	.370	.630	16
13.3	.333	.667	11
13.4	.296	.704	7
13.5	.259	.741	4
13.6	.222	.778	1
13.7	.185	.815	3
13.8	.148	.852	5

USING 11.5 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.5 lb/gal CaCl ₂ , bbl	14.2 lb/gal CaBr ₂ , bbl	
13.9	.111	.889	5
14.0	.074	.926	7
14.1	.037	.963	11
14.2	.000	1.000	15

Table 3.31

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.6 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.6 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
11.6	1.000	.000	50
11.7	.962	.038	49
11.8	.923	.077	49
11.9	.885	.115	48
12.0	.846	.154	47
12.1	.808	.192	45
12.2	.769	.231	44
12.3	.731	.269	42
12.4	.692	.308	40
12.5	.654	.346	38
12.6	.615	.385	37
12.7	.577	.423	35
12.8	.538	.462	32
12.9	.500	.500	30
13.0	.462	.538	26
13.1	.423	.577	22
13.2	.385	.615	20
13.3	.346	.654	17
13.4	.308	.692	14
13.5	.269	.731	12
13.6	.231	.769	8
13.7	.192	.808	4
13.8	.154	.846	4
13.9	.115	.885	6
14.0	.077	.923	8
14.1	.038	.962	12
14.2	.000	1.000	15

Table 3.32

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.7 lb/gal CaCl_2 AND 14.2 lb/gal CaBr_2

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	11.6 lb/gal CaCl_2 , bbl	14.2 lb/gal CaBr_2 , bbl	
11.7	1.000	.000	55
11.8	.960	.040	54
11.9	.920	.080	52
12.0	.880	.120	50
12.1	.840	.160	48
12.2	.800	.200	46
12.3	.760	.240	45
12.4	.720	.280	43
12.5	.680	.320	43
12.6	.640	.360	40
12.7	.600	.400	38
12.8	.560	.440	36
12.9	.520	.480	34
13.0	.480	.520	32
13.1	.440	.560	28
13.2	.400	.600	23
13.3	.360	.640	19
13.4	.320	.680	17
13.5	.280	.720	14
13.6	.240	.760	11
13.7	.200	.800	8
13.8	.160	.840	7
13.9	.120	.880	8
14.0	.080	.920	10
14.1	.040	.960	12
14.2	.000	1.000	15

Table 3.33

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 15.1 lb/gal $\text{CaBr}_2/\text{CaCl}_2$ AND 10.7 lb/gal CaCl_2

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	15.1 lb/gal $\text{CaBr}_2/\text{CaCl}_2$, bbl	10.7 lb/gal CaCl_2 , bbl	
10.7	.000	1.000	-58
10.8	.023	.977	-57
10.9	.045	.955	-57
11.0	.068	.932	-56
11.1	.091	.909	-52
11.2	.114	.886	-48
11.3	.136	.864	-46
11.4	.159	.841	-41
11.5	.182	.818	-37
11.6	.204	.795	-33
11.7	.227	.773	-27
11.8	.250	.750	-21
11.9	.273	.727	-17
12.0	.295	.705	-12
12.1	.318	.682	- 8
12.2	.341	.659	- 2
12.3	.363	.636	4
12.4	.386	.614	9
12.5	.409	.591	13
12.6	.432	.568	17
12.7	.455	.545	21
12.8	.477	.523	25
12.9	.500	.500	28
13.0	.523	.477	31
13.1	.545	.455	33
13.2	.568	.432	35
13.3	.591	.409	37

Table 3.33

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 15.1 lb/gal $\text{CaBr}_2/\text{CaCl}_2$ AND 10.7 lb/gal CaCl_2

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	15.1 lb/gal $\text{CaBr}_2/\text{CaCl}_2$, bbl	10.7 lb/gal CaCl_2 , bbl	
13.4	.614	.386	40
13.5	.636	.363	42
13.6	.659	.341	44
13.7	.682	.318	45
13.8	.705	.295	47
13.9	.727	.273	49
14.0	.750	.250	50
14.1	.773	.227	52
14.2	.795	.204	53
14.3	.818	.182	54
14.4	.841	.159	56
14.5	.864	.136	57
14.6	.886	.114	58
14.7	.909	.091	60
14.8	.932	.068	62
14.9	.955	.045	63
15.0	.977	.023	66
15.1	1.000	.000	68

Table 3.34

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

USING 11.6 lb/gal CaCl_2 , 14.2 lb/gal CaBr_2 , AND
SACKED CaCl_2 (94-97%)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	11.6 lb/gal CaCl_2 bbl	14.2 lb/gal CaBr_2 bbl	CaCl_2 (94-97%) lb	
11.7	.9714	.0254	2.86	45
11.8	.9429	.0507	6.06	51
11.9	.9143	.0762	9.09	52
12.0	.8857	.1016	12.13	54
12.1	.8572	.1269	15.15	55
12.2	.8286	.1524	18.18	55
12.3	.8000	.1778	21.22	56
12.4	.7715	.2032	24.24	56
12.5	.7429	.2286	27.28	57
12.6	.7143	.2540	30.31	57
12.7	.6857	.2794	33.34	58
12.8	.6572	.3048	36.37	58
12.9	.6286	.3302	39.41	59
13.0	.6000	.3556	42.44	59
13.1	.5714	.3810	45.47	60
13.2	.5429	.4064	48.49	60
13.3	.5143	.4318	51.53	60
13.4	.4857	.4572	54.56	61
13.5	.4572	.4826	57.59	61
13.6	.4286	.5080	60.62	62
13.7	.4000	.5334	63.66	62
13.8	.3714	.5589	66.69	63
13.9	.3429	.5842	69.72	63
14.0	.3143	.6069	72.75	64
14.1	.2857	.6351	75.78	64
14.2	.2572	.6604	78.81	64

Table 3.34

CALCIUM CHLORIDE / CALCIUM BROMIDE SOLUTION REQUIREMENTS

**USING 11.6 lb/gal CaCl_2 , 14.2 lb/gal CaBr_2 , AND
SACKED CaCl_2 (94-97%)**

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	11.6lb/gal CaCl_2 bbl	14.2lb/gal CaBr_2 bbl	CaCl_2 (94-97%) lb	
14.3	.2286	.6858	81.84	65
14.4	.2000	.7113	84.88	65
14.5	.1715	.7366	87.90	65
14.6	.1429	.7620	90.94	66
14.7	.1143	.7875	93.97	66
14.8	.0858	.8128	96.99	67
14.9	.0572	.8382	100.03	67
15.0	.0286	.8637	103.06	67
15.1	.0000	.8891	106.10	68

**SAMPLE CALCULATIONS FOR PREPARING $\text{CaCl}_2/\text{CaBr}_2$ BRINE
USING TABLE 3.16**

Determine the material requirements for the preparation of 250 barrels of 13.8 lb/gal $\text{CaCl}_2/\text{CaBr}_2$ brine.

Water requirement: None

14.2 lb/gal CaBr_2 requirement: $250 \text{ bbl} \times .5589 \text{ bbl/bbl} = 139.7 \text{ bbl}$

11.6 lb/gal CaCl_2 requirement: $250 \text{ bbl} \times .3231 \text{ bbl/bbl} = 80.8 \text{ bbl}$

Dry CaCl_2 requirement: $250 \text{ bbl} \times 90.23 \text{ lb/bbl} = 22,558 \text{ lb}$ (282 80-lb sacks)

**SAMPLE CALCULATIONS FOR PREPARING $\text{CaCl}_2/\text{CaBr}_2$ BRINE
USING TABLE 3.28**

Determine the material requirements for the preparation of 250 barrels of 13.8 lb/gal $\text{CaCl}_2/\text{CaBr}_2$ brine.

Water requirement: None

11.3 lb/gal CaCl_2 requirement: $250 \text{ bbl} \times .138 \text{ bbl/bbl} = 34.5 \text{ bbl}$

14.2 lb/gal CaBr_2 requirement: $250 \text{ bbl} \times .862 \text{ bbl/bbl} = 215.5 \text{ bbl}$

Crystallization Point: 2°F

Table 3.34-A

CALCIUM BROMIDE SOLUTION REQUIREMENTS USING SACKED CaBr_2

To make 1 bbl (42 gal)

Density (lb/gal)	bbl H_2O	lbs CaBr_2 (95%)
11.0	.889	150.8
11.1	.885	156.6
11.2	.880	162.4
11.3	.875	168.1
11.4	.870	173.9
11.5	.865	179.7
11.6	.860	185.5
11.7	.855	191.3
11.8	.851	197.0
11.9	.847	202.8
12.0	.843	208.6
12.1	.839	214.4
12.2	.835	220.1
12.3	.830	225.9
12.4	.825	231.7
12.5	.820	237.5
12.6	.816	243.2
12.7	.811	249.0
12.8	.806	254.8
12.9	.801	260.6
13.0	.797	266.4
13.1	.793	272.1
13.2	.788	277.9
13.3	.783	283.7
13.4	.779	289.5
13.5	.774	295.3
13.6	.770	301.0
13.7	.766	306.8
13.8	.761	312.6
13.9	.756	318.4
14.0	.752	324.1
14.1	.748	329.9
14.2	.744	335.7
14.3	.740	341.5

Table 3.35

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 14.2 lb/gal CaBr_2 , 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, AND
SACKED CaCl_2 (94-97%)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	14.2 lb/gal CaBr_2 bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	CaCl_2 (94-97%) lb	
14.4	.9600	.0400	0.00	9
14.4	.9681	.0204	10.98	--
14.4	.9736	.0000	24.15	37
14.5	.9400	.0600	0.00	3
14.5	.9480	.0408	10.75	19
14.5	.9533	.0208	23.65	37
14.5	.9596	.0000	36.70	48
14.6	.9200	.0800	0.00	7
14.6	.9278	.0612	10.52	19
14.6	.9330	.0417	23.14	39
14.6	.9392	.0213	35.92	48
14.6	.9461	.0000	48.92	57
14.7	.9000	.1000	0.00	--
14.7	.9076	.0816	10.29	19
14.7	.9128	.0625	22.64	23
14.7	.9188	.0426	35.14	45
14.7	.9255	.0217	47.86	52
14.7	.9282	.0000	63.83	63
14.8	.8800	.1200	0.00	- 4
14.8	.8875	.1020	10.07	21
14.8	.8925	.0833	22.14	36
14.8	.8983	.0638	34.36	43
14.8	.9050	.0435	46.79	52
14.8	.9076	.0222	62.41	59
14.8	.9071	.0000	80.60	67
14.9	.8600	.1400	0.00	0

Table 3.35

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 14.2 lb/gal CaBr_2 , 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, AND
SACKED CaCl_2 (94-97%)
(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	14.2 lb/gal CaBr_2 bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	CaCl_2 (94-97%) lb	
14.9	.8673	.1224	9.84	--
14.9	.8722	.1042	21.63	32
14.9	.8779	.0851	33.58	--
14.9	.8844	.0652	45.73	52
14.9	.8869	.0444	60.99	--
14.9	.8865	.0227	78.77	64
14.9	.8872	.0000	96.66	68
15.0	.8400	.1600	0.00	--
15.0	.8471	.1429	9.61	27
15.0	.8519	.1250	21.13	41
15.0	.8575	.1064	32.80	54
15.0	.8538	.0870	44.67	57
15.0	.8663	.0667	59.57	--
15.0	.8659	.0455	76.93	--
15.0	.8666	.0233	94.41	66
15.0	.8684	.0000	112.06	69
15.1	.8200	.1800	0.00	- 6
15.1	.8269	.1632	9.38	--
15.1	.8316	.1458	20.63	30
15.1	.8371	.1277	32.01	--
15.1	.8433	.1087	43.60	50
15.1	.8457	.0889	58.16	--
15.1	.8453	.0682	75.10	63
15.1	.8459	.0465	92.16	66
15.1	.8477	.0238	109.39	--
15.1	.8507	.0000	126.87	69

Table 3.36

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

**USING 14.2 lb/gal CaBr_2 BRINE, 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$ BRINE AND
SACKED CaCl_2 (94-97%)**

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	14.2 lb/gal CaBr_2 bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	CaCl_2 (94-97%) lb	
14.3	.9887	----	13.0	+10
14.4	.9754	----	30.6	+36
14.5	.9563	.0133	33.8	+32
14.6	.9420	.0246	37.8	+40
14.7	.9222	.0450	37.2	+40
14.8	.9017	.0680	38.4	+37
14.9	.8811	.0851	38.8	+40
15.0	.8607	.1063	38.5	+39
15.1	.8410	.1270	37.0	+37
15.2	.8210	.1480	36.2	+37
15.3	.8000	.1700	35.2	+38
15.4	.7790	.1910	37.0	+34
15.5	.7600	.2100	44.1	+39
15.6	.7415	.2250	40.0	+40

Table 3.37

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

**USING 14.2 lb/gal CaBr_2 BRINE, 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$ BRINE AND
SACKED CaCl_2 (94-97%)**

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	14.2 lb/gal CaBr_2 bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	CaCl_2 (94-97%) lb	
14.3	.9887	----	13.0	+10
14.4	.9752	.0104	16.0	+18
14.5	.9540	.0320	15.8	+18
14.6	.9346	.0520	15.4	+19
14.7	.9142	.0729	15.1	+14
14.8	.8910	.0901	20.2	+20
14.9	.8707	.1105	19.9	+20
15.0	.8505	.1314	19.4	+19
15.1	.8307	.1520	19.6	+18
15.2	.8110	.1725	19.4	+16
15.3	.7898	.1930	18.0	+16
15.4	.7695	.2124	20.2	+20
15.5	.7496	.2326	22.0	+16
15.6	.7296	.2528	25.0	+19

Table 3.38

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 13.2 lb/gal $\text{CaBr}_2/\text{CaCl}_2$ AND 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	15.1 lb/gal $\text{CaBr}_2/\text{CaCl}_2$, bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	
15.0	.7000	.3000	28
15.1	.6833	.3167	26
15.2	.6777	.3333	24
15.3	.6500	.3500	22
15.4	.6333	.3667	18
15.5	.6167	.3833	15
15.6	.6000	.4000	12
15.7	.5833	.4167	9
15.8	.5667	.4333	0
15.9	.5500	.4500	- 8
16.0	.5333	.4667	- 4
16.1	.5167	.4833	- 3
16.2	.5000	.5000	- 1
16.3	.4833	.5167	0
16.4	.4667	.5333	1
16.5	.4500	.5500	5
16.6	.4333	.5667	7
16.7	.4167	.5833	10
16.8	.4000	.6000	11
16.9	.3833	.6167	12
17.0	.3667	.6333	13
17.1	.3500	.6500	14
17.2	.3333	.6667	14
17.3	.3167	.6833	15
17.4	.3000	.7000	15
17.5	.2833	.7167	15
17.6	.2667	.7333	16

Table 3.38

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 13.2 lb/gal $\text{CaBr}_2/\text{CaCl}_2$ AND 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	15.1 lb/gal $\text{CaBr}_2/\text{CaCl}_2$, bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	
17.7	.2500	.7500	16
17.8	.2333	.7667	17
17.9	.2167	.7833	17
18.0	.2000	.8000	18
18.1	.1833	.8167	18
18.2	.1667	.8333	19
18.3	.1500	.8500	19
18.4	.1333	.8667	19
18.5	.1167	.8833	20
18.6	.1000	.9000	20
18.7	.0833	.9167	20
18.8	.0667	.9333	21
18.9	.0500	.9500	21
19.0	.0333	.9667	21
19.1	.0167	.9833	20
19.2	.0000	1.0000	20

Table 3.39

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 13.7 lb/gal $\text{CaBr}_2/\text{CaCl}_2$ AND 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	13.7 lb/gal $\text{CaBr}_2/\text{CaCl}_2$, bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	
15.0	.7636	.2364	46
15.1	.7454	.2546	43
15.2	.7273	.2727	40
15.3	.7091	.2909	38
15.4	.6909	.3091	36
15.5	.6727	.3273	34
15.6	.6545	.3455	32
15.7	.6364	.3636	30
15.8	.6182	.3818	28
15.9	.6000	.4000	25
16.0	.5818	.4182	22
16.1	.5636	.4364	19
16.2	.5454	.4546	16
16.3	.5273	.4727	13
16.4	.5091	.4909	9
16.5	.4909	.5091	3
16.6	.4727	.5273	4
16.7	.4546	.5454	9
16.8	.4364	.5636	14
16.9	.4182	.5818	19
17.0	.4000	.6000	23
17.1	.3818	.6182	23
17.2	.3636	.6364	23
17.3	.3455	.6545	24
17.4	.3273	.6727	24
17.5	.3091	.6909	25
17.6	.2909	.7091	25

Table 3.39

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 13.7 lb/gal $\text{CaBr}_2/\text{CaCl}_2$ AND 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	13.7 lb/gal $\text{CaBr}_2/\text{CaCl}_2$, bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	
17.7	.2727	.7273	25
17.8	.2546	.7454	26
17.9	.2364	.7636	26
18.0	.2182	.7818	27
18.1	.2000	.8000	27
18.2	.1818	.8182	27
18.3	.1636	.8364	25
18.4	.1455	.8546	25
18.5	.1273	.8727	25
18.6	.1091	.8909	22
18.7	.0909	.9091	21
18.8	.0727	.9273	21
18.9	.0545	.9455	20
19.0	.0364	.9636	19
19.1	.0182	.9818	17
19.2	.0000	.1000	16

Table 3.40

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 14.1 lb/gal $\text{CaBr}_2/\text{CaCl}_2$ AND 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	14.2 lb/gal $\text{CaBr}_2/\text{CaCl}_2$, bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	
15.0	.840	.160	51
15.1	.820	.180	51
15.2	.800	.200	50
15.3	.780	.220	49
15.4	.760	.240	48
15.5	.740	.260	47
15.6	.720	.280	46
15.7	.700	.300	44
15.8	.680	.320	43
15.9	.660	.340	41
16.0	.640	.360	40
16.1	.620	.380	40
16.2	.600	.400	39
16.3	.580	.420	38
16.4	.560	.440	37
16.5	.540	.460	36
16.6	.520	.480	35
16.7	.500	.500	34
16.8	.480	.520	33
16.9	.460	.540	32
17.0	.440	.560	32
17.1	.420	.580	32
17.2	.400	.600	31
17.3	.380	.620	30
17.4	.360	.640	30
17.5	.340	.660	30
17.6	.320	.680	29

Table 3.40

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 14.1 lb/gal $\text{CaBr}_2/\text{CaCl}_2^*$ AND 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	14.2 lb/gal $\text{CaBr}_2/\text{CaCl}_2$, bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	
17.7	.300	.700	29
17.8	.280	.720	29
17.9	.260	.740	28
18.0	.240	.760	27
18.1	.220	.780	27
18.2	.200	.800	27
18.3	.180	.820	27
18.4	.160	.840	26
18.5	.140	.860	25
18.6	.120	.880	25
18.7	.100	.900	24
18.8	.080	.920	23
18.9	.060	.940	23
19.0	.040	.960	22
19.1	.020	.980	21
19.2	.000	1.000	20

* 14.2 $\text{CaBr}_2/\text{CaCl}_2$ made from 11.6 CaCl_2 + 14.2 CaBr_2 + sacked CaCl_2 (94-97%)

Table 3.41

CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 14.2 lb/gal CaBr_2 AND 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	14.2 lb/gal CaBr_2 , bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	
15.0	.840	.160	-22
15.1	.820	.180	-25
15.2	.800	.200	-27
15.3	.780	.220	-29
15.4	.760	.240	-32
15.5	.740	.260	-34
15.6	.720	.280	-35
15.7	.700	.300	-38
15.8	.680	.320	-40
15.9	.660	.340	-37
16.0	.640	.360	-33
16.1	.620	.380	-30
16.2	.600	.400	-26
16.3	.580	.420	-23
16.4	.560	.440	-20
16.5	.540	.460	-16
16.6	.520	.480	-11
16.7	.500	.500	- 8
16.8	.480	.520	- 6
16.9	.460	.540	- 4
17.0	.440	.560	- 4
17.1	.420	.580	- 2
17.2	.400	.600	0
17.3	.380	.620	2
17.4	.360	.640	4
17.5	.340	.660	5
17.6	.320	.680	5

Table 3.41

CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 14.2 lb/gal CaBr_2 AND 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	14.2 lb/gal CaBr_2 , bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	
17.7	.300	.700	6
17.8	.280	.720	7
17.9	.260	.740	7
18.0	.240	.760	9
18.1	.220	.780	10
18.2	.200	.800	11
18.3	.180	.820	13
18.4	.160	.840	15
18.5	.140	.860	17
18.6	.120	.880	19
18.7	.100	.900	21
18.8	.080	.920	23
19.0	.060	.940	20
19.1	.040	.960	21
19.2	.020	.980	18
19.3	.000	1.000	16

Table 3.42

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 14.6 lb/gal $\text{CaCl}_2/\text{CaBr}_2$ AND 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	14.6 lb/gal $\text{CaCl}_2/\text{CaBr}_2$, bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	
14.6	1.000	.000	63
14.7	.978	.022	63
14.8	.957	.043	63
14.9	.935	.065	62
15.0	.913	.087	62
15.1	.891	.109	62
15.2	.870	.130	61
15.3	.848	.152	61
15.4	.826	.174	60
15.5	.804	.196	60
15.6	.783	.217	59
15.7	.761	.239	59
15.8	.739	.261	58
15.9	.717	.283	58
16.0	.696	.304	57
16.1	.674	.326	55
16.2	.652	.348	53
16.3	.630	.370	51
16.4	.609	.391	48
16.5	.587	.413	45
16.6	.565	.435	43
16.7	.543	.457	37
16.8	.522	.478	32
16.9	.500	.500	30
17.0	.478	.522	34
17.1	.457	.543	38
17.2	.435	.565	43

Table 3.42

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 14.6 lb/gal $\text{CaCl}_2/\text{CaBr}_2$ AND 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)		Crystallization Point (LCTD), °F
	14.6 lb/gal $\text{CaCl}_2/\text{CaBr}_2$, bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	
17.3	.413	.587	45
17.4	.391	.609	46
17.5	.370	.630	47
17.6	.348	.652	47
17.7	.326	.674	47
17.8	.304	.696	47
17.9	.283	.717	46
18.0	.261	.739	44
18.1	.239	.761	43
18.2	.217	.783	41
18.3	.196	.804	39
18.4	.174	.826	37
18.5	.152	.848	35
18.6	.130	.870	34
18.7	.109	.891	32
18.8	.087	.913	29
18.9	.065	.935	26
19.0	.043	.957	23
19.1	.022	.978	20
19.2	.000	1.000	16

Table 3.43

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

USING 14.2 lb/gal $\text{CaCl}_2/\text{CaBr}_2$ BRINE, 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$ BRINE AND
SACKED CaCl_2 (94%)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	14.2 lb/gal $\text{CaCl}_2/\text{CaBr}_2$, bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	94% CaCl_2 , lb	
15.0	.8891	.000	106	+64
15.1	.8678	.024	103	62
15.2	.8464	.048	101	61
15.3	.8260	.071	98	59
15.4	.8046	.095	96	59
15.5	.7833	.119	93	59
15.6	.7620	.143	91	58
15.7	.7406	.167	88	57
15.8	.7202	.190	86	55
15.9	.6988	.214	83	54
16.0	.6775	.238	81	53
16.1	.6562	.262	78	52
16.2	.6348	.286	76	50
16.3	.6135	.310	73	50
16.4	.5930	.333	71	49
16.5	.5717	.357	68	47
16.6	.5504	.381	66	46
16.7	.5263	.405	63	43
16.8	.5077	.429	61	40
16.9	.4872	.452	58	36
17.0	.4859	.476	56	32
17.1	.4446	.500	53	28
17.2	.4232	.524	50	31
17.3	.4019	.548	48	35

Table 3.43

CALCIUM CHLORIDE / CALCIUM BROMIDE / ZINC BROMIDE SOLUTION REQUIREMENTS

**USING 14.2 lb/gal $\text{CaCl}_2/\text{CaBr}_2$ BRINE, 19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$ BRINE AND
SACKED CaCl_2 (94%)**

(Continued)

Brine Density at 70° F lb/gal	To make 1 bbl (42 gal)			Crystallization Point (LCTD), °F
	14.2 lb/gal $\text{CaCl}_2/\text{CaBr}_2$, bbl	19.2 lb/gal $\text{ZnBr}_2/\text{CaBr}_2$, bbl	94% CaCl_2 , lb	
17.4	.3814	.571	45	37
17.5	.3601	.592	43	41
17.6	.3387	.619	40	45
17.7	.3174	.643	38	44
17.8	.2961	.667	35	44
17.9	.2756	.690	33	43
18.0	.2543	.714	30	43
18.1	.2329	.738	28	42
18.2	.2116	.762	25	41
18.3	.1903	.786	23	37
18.4	.1689	.810	20	35
18.5	.1485	.833	18	32
18.6	.1271	.857	15	28
18.7	.1058	.881	13	25
18.8	.0845	.905	10	23
18.9	.0631	.929	8	18
19.0	.0427	.952	5	18
19.1	.0213	.976	3	17
19.2	.0000	1.000	0	16

BRINE DENSITY DETERMINATION

Equipment

1. Glass hydrometer
2. Mercury thermometer
3. Glass cylinder large enough to accommodate the hydrometer
4. Bucket of ice or refrigerator
5. Deaerator (optional)

Test Procedure

1. Deaerate the fluid sample to be measured.
Either:
 - A. Allow the sample to stand 3 to 5 minutes
 - B. Use a Deaerator:
 - (1) Pour the sample into the deaerator.
 - (2) Secure the top of the container.
 - (3) Agitate the sample while operating the vacuum group.
 - (4) Continue until the hand-operated vacuum pump can no longer be pumped.
 - (5) Pull the release valve.
 - (6) Open the container.
2. Equilibrate the fluid at 70°F, or other reference temperature, in a refrigerator or ice bath.
3. Fill the glass cylinder to within 1-2 inches of the top by pouring slowly down the side.
4. Immerse the hydrometer slowly into the samples. **DO NOT DROP THE HYDROMETER INTO THE SAMPLE.**
5. Spin the hydrometer and take the reading when the hydrometer has come to rest. Read the hydrometer scale at the bottom of the meniscus.

Note: Because the walls of the glass cylinder are water wet, the top of the fluid will have a curved surface. The curved surface is referred to as the meniscus. The correct hydrometer reading will be aligned with the surface of the fluid which, when viewed from the side, is the bottom boundary of the meniscus.

Reporting Results

1. Convert the hydrometer reading (specific gravity) to density in pounds per gallon (lb/gal):

- A. Multiply the hydrometer reading by 8.33.

Example:

Specific gravity = 1.370

$1.370 \times 8.33 = 11.4$

Density = 11.4 lb/gal

2. If a 70°F temperature is unattainable, refer to the appropriate brine density versus temperature graph to determine the reference density. See figure 3.2 - 3.5.

- A. Locate the temperature at which the brine was measured on the lower axis.
- B. Follow the line upward to measured density.
- C. Use a straight edge to identify a line parallel to the nearest horizontal line on the chart.
- D. Follow the parallel to the 70°F line and read the density, using the left axis as a guide.

Example:

The density of CaCl_2 brine was determined to be 11.22 lb/gal at 90°F. The equivalent density at 70°F is 11.5 lb/gal.

CRYSTALLIZATION POINT DETERMINATION

Equipment

1. Mercury thermometer
2. 50 ml glass cylinder
3. Bucket of ice or refrigerator

Test Procedure

1. Pour a 30 ml sample of the brine into a 50 ml cylinder.
2. Cool the sample, either:
 - A. In a refrigerator
 - B. In a container of ice:
 - (1) Place cylinder in container
 - (2) Fill container with ice.
 - (3) Add salt over ice.
 - (4) Rotate cylinder in ice.
3. Begin checking temperature of fluid.
4. As fluid temperature approaches anticipated crystallization point, remove cylinder from ice and check formation of crystals.
5. Continue cooling and checking fluid until the first crystal appears.
6. Record fluid temperature at which the first crystal appears. This is the FCTA (first crystal to appear) temperature.
7. After crystals have formed, remove the cylinder of fluid from the ice and stir while allowing it to warm at room temperature.
8. Record the temperature at which the last crystal dissolves. This is the LCTD (last crystal to dissolve) temperature.

Reporting Results

Report the crystallization point at the thermometer reading at which the last crystal dissolved.

DISPLACEMENT

Complete displacement of the fluid already in the hole is critical to the success of every completion/workover operation. Proper displacement procedures should be followed to remove all solids from the hole and to avoid mixing the brine fluid with the drilling fluid previously in the hole.

INDIRECT VS. DIRECT DISPLACEMENT

Two different displacement procedures are outlined below. They are indirect displacement and direct displacement. The choice of procedure depends on casing-tubing strengths and cement bond log results.

If the bond logs and casing strength data indicate that the casing will withstand a calculated pressure differential, the indirect displacement procedures should be used. (Pressure differential = bottom hole pressure - hydrostatic head due to salt water). This procedure uses large volumes of seawater or fresh water to flush the well, resulting in a clean, solids-free displacement, reduced spacer costs, and lower filtration costs. When applying the indirect method (reverse circulation) be sure that the pumping pressure will not exceed the collapse or burst strength of the casing.

If bond logs indicate that the casing will not withstand the differential pressure, the direct displacement pressure should be used. This method does not obtain a clean displacement and expensive filtering will be necessary. However, undesirable pressure situations are eliminated because this procedure maintains a constant hydrostatic head.

PILLS AND SPACERS

Both direct and indirect displacement procedures make use of pills and spacers for effective hole cleaning and separation of fluids. The primary purpose of a spacer is to provide a complete separation of two incompatible fluids. The spacer must be compatible with both the displaced fluid (fluid coming out) and the displacing fluid (fluid going in).

Cleaning pills are used to sweep debris out of the hole. Two types of cleaning pills may be used. A basic cleaning pill is composed of brine viscosified with VI 1000 S (HEC). A scouring pill, used to remove mud cake from the inside of the casing, consists of water, WW 1000 L (a well wash) and course sand. The scouring pill must be preceded and followed by a viscous spacer to prevent mixing with other fluids.

INDIRECT DISPLACEMENT PROCEDURE

1. Run a bit and scraper.
2. Condition and thin the mud as much as possible while maintaining correct rheological properties. Circulate the mud and reciprocate the tubing during this process.
3. Pump seawater or fresh water down the annulus and up the tubing no faster than 2 bbl/min. Store the displaced mud into the desired reserve tank. The reserve circulation reduces intermingling of the mud and water. Pumping fluid faster than 2 bbl/min. creates turbulent flow and increases intermingling of the mud and water.
4. Prepare a 50 barrel pill of fresh water and caustic soda with pH of 12 to 13. Circulate this pill slowly through the entire system for two circulations. Rotate and reciprocate the pipe while circulating. The high pH helps dissolve the wall cake from the casing.
5. Chase the pill with clean water and flush until the water is clear.
6. Prepare a 20 barrel spacer of the filtered water and VI 1000 D (HEC) with funnel viscosity of 150 - 200 sec/qt. Reverse circulate the spacer, pumping at 1 to 2 bbl/min. Follow with the completion fluid.
7. Pump until the density pumped in equals the density in the flow line. Dump the spacer.
8. Place the filtration unit on line and begin filter brine.

DIRECT DISPLACEMENT

Direct displacement is a somewhat tedious procedure which involves using a number of spacers in line. Each spacer has a specific use. (See the Spacer Section of manual for additional information.)

CALCULATIONS TO INCREASE THE DENSITY OF A FLUID USING SALT

Because salts are soluble in water, it may be difficult in many cases to determine the volume increase resulting from adding salt to water or a water-based fluid. This is particularly true of salts such as CaCl_2 , whose specific gravity changes with the concentration in the solution. Therefore, we recommend the use of the tables and graphs supplied instead of a formula.

In many cases salt may be added until the desired density is obtained, realizing there will be an increase in volume. This increase will be less than would be caused by adding a comparable amount of BA 0005 S (ground Calcium Carbonate) weighting material/bridging agent or barite weighting material.

WEIGHTING UP USING BA 0005 S WEIGHTING MATERIAL/BRIDGING AGENT

Desired Volume or Density Calculations

To make a desired volume (V_F) or density (D_F) using BA 0005 S weighting material/bridging agent as the weighting material and a fluid of density D_1 .

$$V_c = \frac{18.9 V_F (D_F - D_1)}{22.5 - D_1}$$

Where

V_c = Volume of BA 0005 S weighting material/bridging agent (number of 50 lbs sacks needed)

V_F = Desired final volume of fluid (bbl)

D_F = Density of final volume

D_1 = Density of initial fluid to be used in makeup

Volume of initial fluid (V_1) necessary to end up with correct final volume:

$$V_1 = \frac{V_F - V_c}{18.9}$$

Example:

Determine how many sacks of BA 0005 S weighting material/bridging agent are needed to make 500 bbl of 13.5 lb/gal fluid from a 9.0 lb/gal brine.

$$V_c = \frac{18.9 \times 500 (13.5 - 9.0)}{22.5 - 9.0} \quad V_c = \frac{42525}{13.5} = 3150 \text{ sacks}$$

What is the starting volume of 9.0 lb/gal brine?

$$V_1 = \text{Starting volume}$$

$$V_1 = 500 - \frac{3150}{18.9}$$

$$V_1 = 333 \text{ bbl}$$

So, 333 bbl of 9.0 lb/gal brine and 3150 sacks of BA 0005 S weighting material/bridging agent will yield 500 bbl of 13.5 lb/gal fluid.

How to Increase the Density of a Known Volume (V_1) of Fluid (V_1).

$$V_c = \frac{18.9 V_1 (D_F - D_1)}{22.5 - D_F}$$

Where:

V_c = Volume of BA 0005 S weighting material/bridging agent
(50 lb sacks)

V_1 = Volume of fluid to be weighted up

D_1 = Density of fluid to be weighted up

D_F = Final density desired

The volume increase due to addition of BA 0005 S weighting material/bridging agent will result in final Volume (V_F).

$$V_F = V_1 + \frac{V_c}{18.9}$$

Example:

Increase the density of 300 bbl of 11.0 lb/gal fluid to 12.5 lb/gal.

$$V_c = \frac{18.9 \times 300 (12.5 - 11.0)}{22.5 - 12.5} \quad V_c = \frac{8505}{10} = 850.5 \text{ sacks}$$

The final volume of 12.5 lb/gal fluid will be

$$V_F = 300 + \frac{850.5}{18.9} \quad V_F = 345 \text{ bbl}$$

So, 300 bbl of 11.0 lb/gal fluid and 850.5 sacks of BA 0005 S weighting material/bridging agent will yield 345 bbl of 12.5 lb/gal fluid.

To Decrease the Density (D_1) of a Known Volume of Fluid (V_1) Using Volume (V_D) of Dilution Fluid

$$V_D = \frac{V_1 (D_1 - D_F)}{D_F - D_D}$$

Where:

- V_D = Volume of dilution fluid in bbl
- V_1 = Volume of starting fluid in bbl
- D_1 = Density of starting fluid in lb/gal
- D_D = Density of dilution in lb/gal
- D_F = Desired density of final fluid

The final volume of the mixed fluid (V_F) is

$$V_F = V_D + V_1$$

Example:

Dilute 400 bbl of a 14.5 lb/gal fluid to 12.0 lb/gal with a 9.0 lb/gal brine.

$$V_D = \frac{400 (14.5 - 12.0)}{12.0 - 9.0} \quad V_D = \frac{1000}{3} \quad V_D = 333 \text{ bbl}$$

The final volume is

$$V_F = 400 + 333 \quad V_F = 733 \text{ bbl}$$

So, 333 bbl of 9.0 lb/gal brine added to 400 bbl of 14.5 lb/gal fluid will yield 733 bbl of 12.0 lb/gal fluid.

How to Increase the Density of a Known Volume of Fluid With a Denser Fluid

$$V_D = \frac{V_1 (D_F - D_1)}{D_D - D_F}$$

The nomenclature is the one we have been using. Final volume is again given by the formula.

$$V_F = V_D + V_1$$

To determine the volume change factor at elevated temperatures, find the value for the temperature of interest and follow the line up to where it intersects the appropriate sloped line. Read across to find the volume change factor on the vertical scale. The new volume will be

$$V_2 = V_1 \times F_{vc}$$

The new density will be

$$D_2 = \frac{D_1}{F_{vc}}$$

Where

- V_2 = Volume at elevated temperature, in bbl
- V_1 = Volume at 60°F, in bbl
- D_2 = Density at elevated temperature, in lb/bbl
- D_1 = Density at 60°F, in bbl
- F_{vc} = Volume change factor from graph

Table 7.1

Density of BA 0005 S Weighting Material/Bridging Agent Expressed in Various Units

$$2.7 \text{ g/cc} = 22.5 \text{ lb/gal} = 18.9 \text{ 50-lb sacks per barrel}$$

Calculating the Volume of Cylindrical Mixing Tanks

1. Measure the diameter of the tank in feet (D).
2. Measure the depth of height of the tank in feet (H).
3. Calculate the total volume of the tank.

$$\text{Volume, bbl} = \frac{D^2}{2} \times \frac{3.14 \times H}{5.61}$$

4. To calculate the number of barrels per foot or barrels per inch.

$$\text{Barrels/ft} = \frac{\text{Volume of tank}}{H} \quad \text{Barrels/inch} = \frac{\text{Barrels/ft}}{12}$$

SALT WATER CONSTANTS

Table 7.2

Maximum Solubility of Sodium Chloride in Water

Temperature, °C	Temperature, °F	Percent NaCl by Weight in Saturated Solution
0	32	26.3
20	68	26.5
50	122	27.0
100	212	28.5

Table 7.3

Densities of Aqueous Sodium Chloride Solutions at 20°C (68°F)

Sp Gr 20° ---C 4°	Percent NaCl by wt	grams NaCl per 100 cm ³ of solution	lb NaCl per ft ³	lb NaCl per gal	lb NaCl per bbl
1.0053	1	1.01	0.628	0.084	3.52
1.0125	2	2.03	1.260	0.169	7.10
1.0268	4	4.11	2.560	0.343	14.40
1.0413	6	6.25	3.900	0.521	21.90
1.0559	8	8.45	5.270	0.705	29.61
1.0707	10	10.71	6.680	0.894	37.53
1.0857	12	13.03	8.130	1.090	45.65
1.1009	14	15.41	9.620	1.290	54.01
1.1162	16	17.86	11.150	1.490	62.58
1.1319	18	20.37	12.720	1.700	71.40
1.1478	20	22.96	14.330	1.920	80.47
1.1640	22	25.61	15.990	2.140	89.75
1.1804	24	28.33	17.690	2.360	99.29
1.1972	26	31.13	19.430	2.600	109.12

Table 5.1

LOST CIRCULATION PILLS

Bridging Agent	Formation	Carrier Fluid	Viscosifier
BA 0005 S	Carbonate and sandstone not acid sensitive	Viscous water and brine	VI 1000 S
BA 0150 S			VI 1000 D
BA 0600 S		Oil based fluid	VI 2000 D
BS 1000 S	Dry gas reservoirs, acid	Viscous saturated brine*	VI 1000 S, VI 1000 D
BS 2000 S	sensitive formations		VI 2000 D
		Oil based fluid	VO 1000 S
BO 1000 S Fine, Medium Coarse, Granule	Oil and gas condensate zones with BHT < 360°F	Viscous water or brine with water wetting surfactant	VI 1000 S**

* Brine must be saturated so that the bridging particles remain insoluble.

** Only VI 1000 S should be used as the viscosifier with VO 1000 S. VI 1000 D & VI 2000 D contain liquid hydrocarbon which will dissolve some of the BO 1000 S particles.

LOST CIRCULATION IN PAY ZONES

Loss of fluids to permeable formations is the most common problem in drilling and completing a well. Lost circulation may reduce the effective hydrostatic pressure in the annulus and cause more serious problems such as well kick, blowout, corrosive gas flow, and pipe sticking. Losing fluids into the pay zone can severely impair productivity and lower profits.

Lost circulation occurs when the borehole wall is permeable and pressure differential is applied toward the formation. In some cases, decreasing differential pressure by reducing the fluid density, pumping pressure and fluid viscosity will stop fluid loss and regain circulation. However, the most effective method is to reduce the permeability of the borehole wall by introducing properly sized bridging material (lost circulation material). A non-damaging lost circulation pill should be formulated using a properly sized, degradable bridging agent and a high viscosity carrier fluid.

BRIDGING AGENTS

Only degradable materials should be used to control lost circulation in payzones. Conventional lost circulation materials such as mica, vegetable fiber, cotton seed hulls, and ground rubber are not degradable and may cause permanent damage. These materials must not be used for temporary sealing of potential payzones. SYNERGY offers three degradable bridging agents: Calcium Carbonate, soluble Salts and Oil Soluble Resins. The Calcium Carbonate is graded as BA 0005 S, BA 0050 S, BA 0600 S and BA 2300 S. The Soluble Salt is graded as SB 1000 S and SB 2000 S. Oil soluble resins are graded as Fine, Medium, coarse and Granule. Recommended uses of each are given in Table 5.1.

Properly sized bridging material must be selected to block the formation pores effectively at the wellbore face. Effective sealing by the lost circulation pill is governed by the selected particle size distribution of the bridging particles and not the concentration. Particles should have a broad size range, and 5 to 10% of the added particles should be at least one third the average formation pore size to establish the desired bridging mechanism. (Refer to the particle size distribution chart for the chosen bridging agent). Consult with your reservoir engineer for the proper particle size selection required for a non-penetrating fluid.

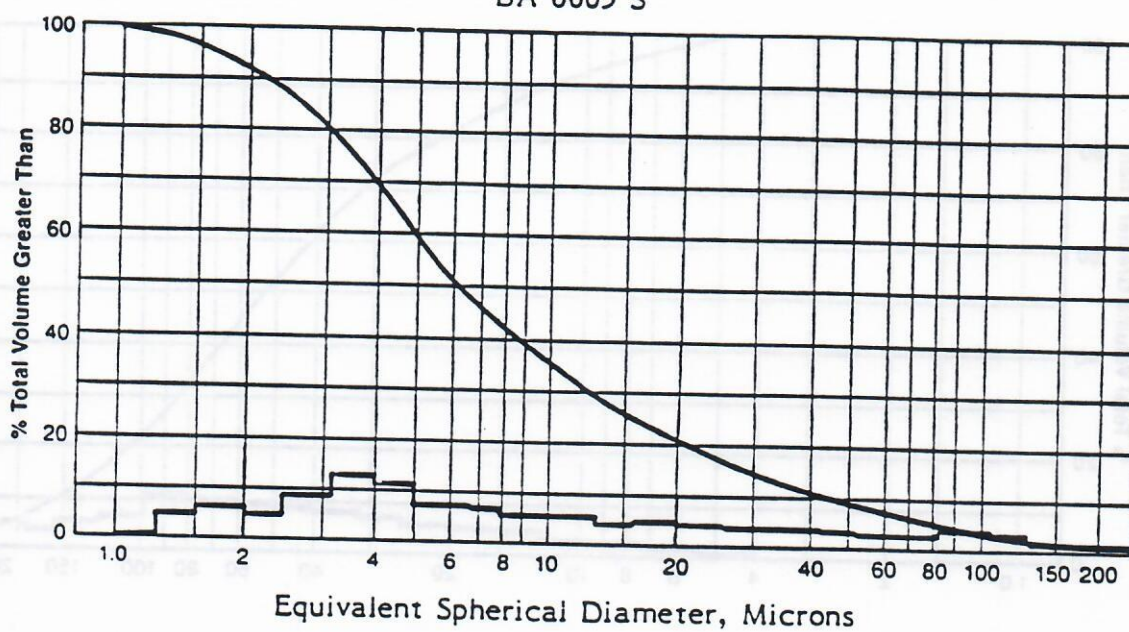
CARRIER FLUIDS

High viscosity (150 to 300 sec/qt) carrier fluid may be prepared by mixing a non-damaging, degradable polymer such as VI 1000 S, VI 1000 D or VI 2000 D with clean makeup water or brine. Good mixing and agitation are essential to prevent "fisheyes" or lumping. Table 5.1 shows the recommended carrier fluid and viscosifier for each application.

APPLICATION OF LOST CIRCULATION PILLS

Lost circulation pills should be spotted at the zone of loss by pumping the pill down hole at a rate that will jam the particles quickly at the entrance of the formation flow channels. Very slow pumping may allow the bridging particles to seep into the zone. To minimize loss of fluid and establish the closest possible packing to the wellbore, do not squeeze the bridging material into the formation. This will prevent formation damage and allow the pill to be cleaned up when the well is produced if fluid is being lost to the pay zone.

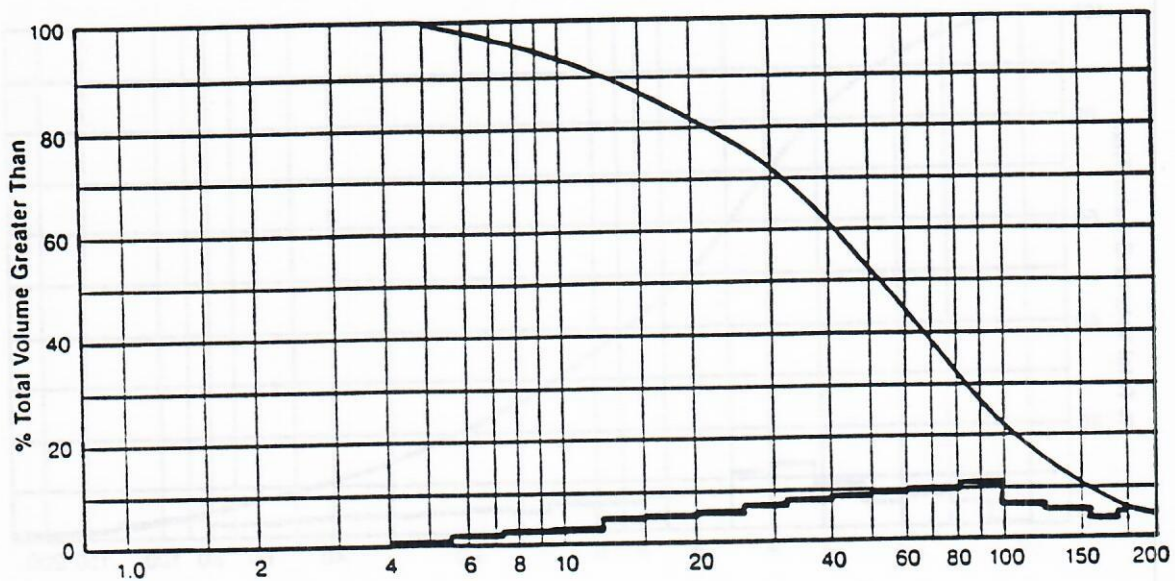
Figure 2.8
Typical Particle Size Distribution*
BA 0005 S



Equivalent Spherical Diameter μ	% Greater than, By Volume
1	100
2	92
3	78
4	66
5	55
6	48
8	41
10	36
13	30
16	26
20	21
25	17
32	14
40	11
51	9
64	7
81	6
102	3
128	1
161	0

*Determined by Coulter Counter

Figure 2.9
Typical Particle Size Distribution*
BA 0050 S

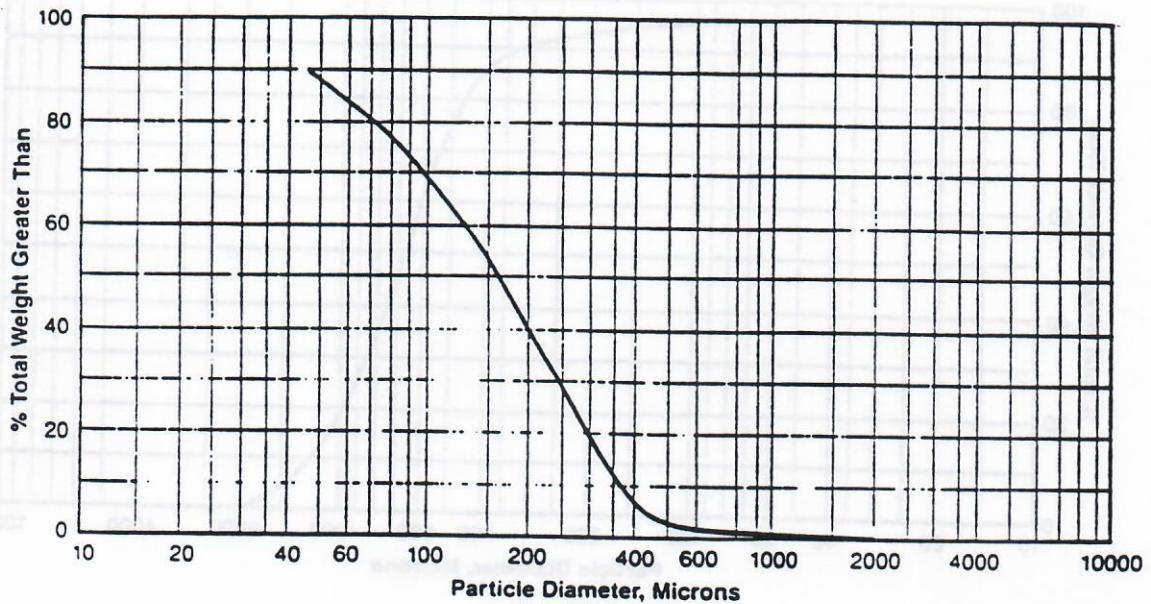


Equivalent Spherical Diameter, Microns

Equivalent Spherical Diameter μ	% Greater than, By Volume
4	100
5	99
6	98
8	96
10	94
13	90
16	87
20	82
25	77
32	70
40	62
51	52
64	43
81	33
102	22
128	16
161	10
203	5

*Determined by Coulter Counter

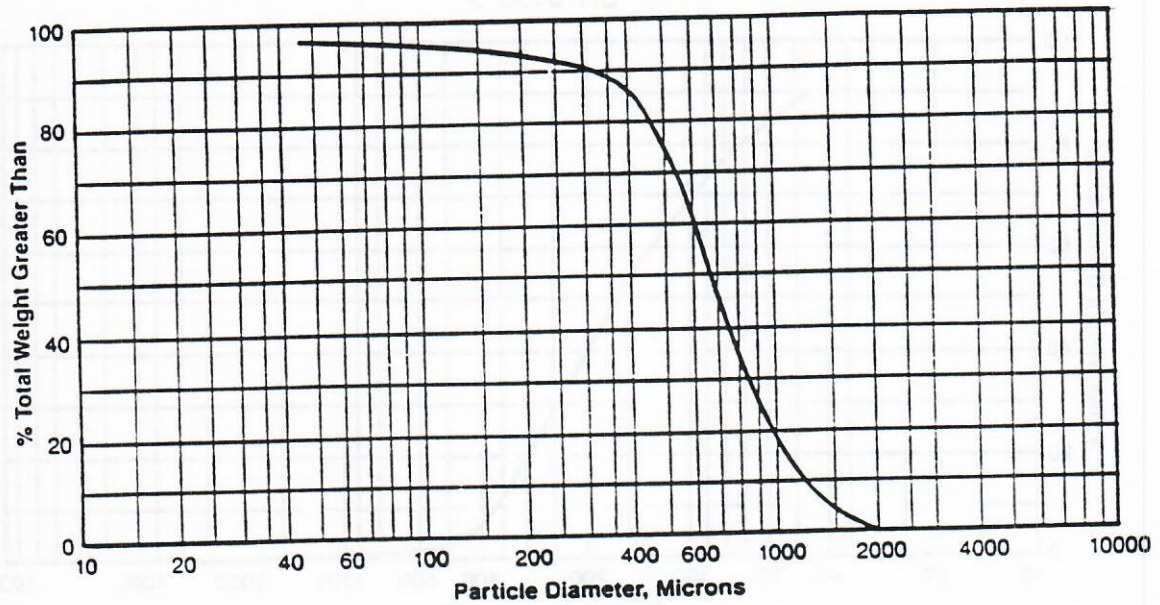
Figure 2.10
Typical Particle Size Distribution*
BA 0150 S



Mesh Size	Micron Size	% Greater Than, by Weight
325	45	90
200	75	79
100	150	55
80	180	45
60	250	29
50	300	18
40	420	2
30	595	1
20	841	1
10	2000	0

*Determined by Screen Analysis

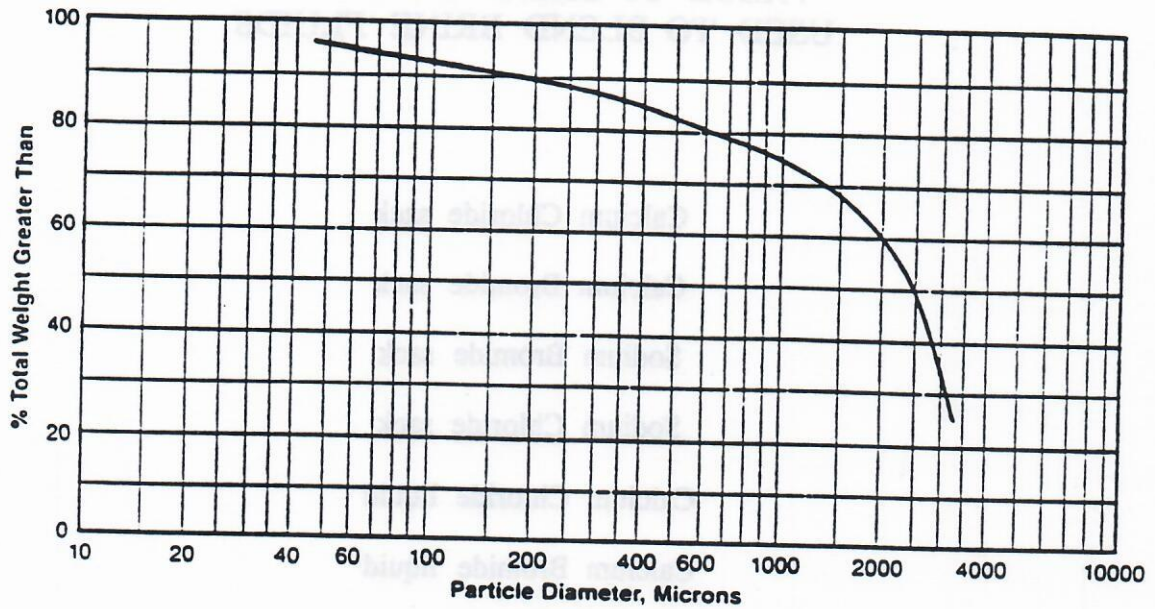
Figure 2.11
Typical Particle Size Distribution*
BA 0600 S



Mesh Size	Micron Size	% Greater Than, by Weight
325	45	97
200	75	96
100	150	95
80	180	94
60	250	92
50	300	91
40	420	86
30	595	66
20	841	32
10	2000	0

*Determined by Screen Analysis

Figure 2.12
Typical Particle Size Distribution*
BA 2300 S



Mesh Size	Micron Size	% Greater Than, by Weight
325	45	96
200	75	94
100	150	91
80	180	90
60	250	88
50	300	86
40	420	84
30	595	81
20	841	78
10	2000	63
8	2380	53
6	3360	25

*Determined by Screen Analysis

VALUE OF BASIC MATERIALS USED TO BLEND BRINE FLUIDS

Calcium Chloride sack

Calcium Bromide sack

Sodium Bromide sack

Sodium Chloride sack

Calcium Chloride liquid

Calcium Bromide liquid

Calcium Bromide - Zinc Bromide liquid

13.6 ppg (1.63 SG) Summer Blend

Crystallization 62°F (16.6°C)

Table 3.34

Calcium Bromide	14.2 ppg (1.70 SG)	0.5080 bbls
Calcium Chloride	sack	60.62 lbs.
Calcium Chloride	11.6 ppg (1.39 SG)	0.4286 bbls

15.1 ppg (1.81 SG) Summer Blend

Crystallization 68°F (20°C)

Table 3.34

Calcium Chloride	11.6 ppg (1.39 SG)	0
Calcium Bromide	14.2 ppg (1.70 SG)	0.8891 bbl
Calcium Chloride	sack	106.10 ppb

15.1 ppg (1.81 SG) Winter Blend

Crystallization -6°F (-21°C)

Table 3.35

Calcium Bromide	14.2 ppg (1.70 SG)	0.8200 bbl
Zinc Bromide	19.2 ppg (2.30 SG)	0.1800 bbl

15.1 ppg (1.81 SG) Calcium Bromide - Calcium Chloride

Crystallization 69°F (20°C)

Table 3.35

Calcium Bromide	14.2 ppg (1.70 SG)	0.8507 bbl
Calcium Chloride	sack	126.87 lbs

18.2 ppg (2.18 SG) Calcium Bromide / Zinc Bromide Blend

Crystallization 11°F (-12°C)

Table 3.41

Calcium Bromide	14.2 ppg (1.70 SG)	0.200 bbl
Zinc Bromide	19.2 ppg (2.30 SG)	0.800 bbl

18.2 ppg (2.18 SG) Calcium Bromide / Zinc Bromide Blend

Crystallization 27°F (-3°C)

Table 3.40

CaBr ₂ / CaCl ₂	14.2 ppg (1.70 SG)	0.200 bbl
Zinc Bromide	19.2 ppg (2.30 SG)	0.800 bbl

14.2 ppg (1.70 SG) CaBr_2 / CaCl_2 from Table 3.34

Calcium Chloride	11.6 ppg (1.39 SG)	0.2575 bbl
Calcium Bromide	14.2 ppg (1.70 SG)	0.6604 bbl
Calcium Chloride	sack	78.81 lbs

**18.2 ppg (2.18 SG) Calcium Chloride - Calcium Bromide -
Zinc Bromide Blend**

Crystallization 41°F (5°C)

14.2 ppg (1.70 SG) $\text{CaCl}_2/\text{CaBr}_2$ from Table 3.34

Table 3.43

$\text{CaCl}_2/\text{CaBr}_2$	14.2 ppg (1.70 SG)	0.2116 bbl
Zinc Bromide	19.2 ppg (2.30 SG)	0.762 bbl
Calcium Chloride	sack	25.0 lbs

41°F

27°F

11°F

13.6 ppg Winter Blend

Crystallization -14°F

Table 3.25

Calcium Chloride	11.0 ppg	0.187 bbls.
Calcium Bromide	14.2 ppg	0.813 bbls.

16.5 ppg (1.98 SG) Winter Blend

Crystallization 3°F (-16°C)

Table 3.39

Calcium Bromide	13.7 ppg (1.64 SG)	0.4909 bbl (.078 m ³)
Zinc Bromide	19.2 ppg (2.30 SG)	0.5091 bbl (.081 m ³)

For this formulation: Pilot Test

20 formulations for 13.7 ppg (1.64 SG) CaCl₂/CaBr₂ listed.

Tables

3.15	3.16	3.17	3.18	3.19
3.20	3.21	3.22	3.23	3.24
3.25	3.26	3.27	3.28	3.29
3.30	3.31	3.32	3.33	3.34

12.3 ppg (1.47 SG) Sodium Bromide

Table 3.6

Water	0.818 bbl (.130 m ³)
Sodium Chloride	16.3 lbs
Sodium Bromide	214.0 lbs

14.2 ppg (1.70 SG) Calcium Bromide

Using Sacked CaBr₂

Table 3.345

Water	.774 bbl (.133 m ³)
Calcium Bromide	sacked 335.7 lbs

EXAMPLE OF MIXING CALCULATIONS

ALTERNATIVE A

0.744 bbl (.118 m³) Water

336 Pounds CaBr₂

0.720 bbl (.114 m³) 14.2 ppg (1.70 SG)
CaBr₂

0.280 bbl (.044 m³) 19.2 ppg (2.30 SG)
ZnBr₂

15.6 ppg (1.87 SG) Brine

-35°F (-37°C) Crystallization Point

\$ 400.00

18% Difference in Price

ALTERNATIVE B

0.8637 (.137 m³) bbls 14.2 ppg (1.70 SG)
CaBr₂

108.67 Pounds CaCl₂

0.024 (.004 m³) bbls H₂O

0.857 bbls (.136 m³) 15.0 ppg (1.80 SG)
CaBr₂

0.143 bbls (.023 m³) 19.2 ppg (2.30 SG)
ZnBr₂

15.6 ppg (1.87 SG) Brine

58°F (14°C) Crystallization Point

\$ 327.00

**CARE AND MAINTENANCE OF BRINES
IN AN OILFIELD APPLICATION**

"CLEAR COMPLETION FLUIDS IN A COMPREHENSIVE
PROGRAM OF FORMATION DAMAGE CONTROL HAS
CONTRIBUTED TO DRAMATIC INCREASES IN PRODUCTION
RATES OVER CONVENTIONAL METHODS."

"THE INDUSTRY ACCEPTS THE FACT THAT
CLEAN BRINES ENHANCE PRODUCTION."

"NOW, THE INDUSTRY HAS TO FIND A WAY TO
KEEP BRINES CLEAN DURING COMPLETION
AND WORKOVER PROCESS."

WHY FILTER?

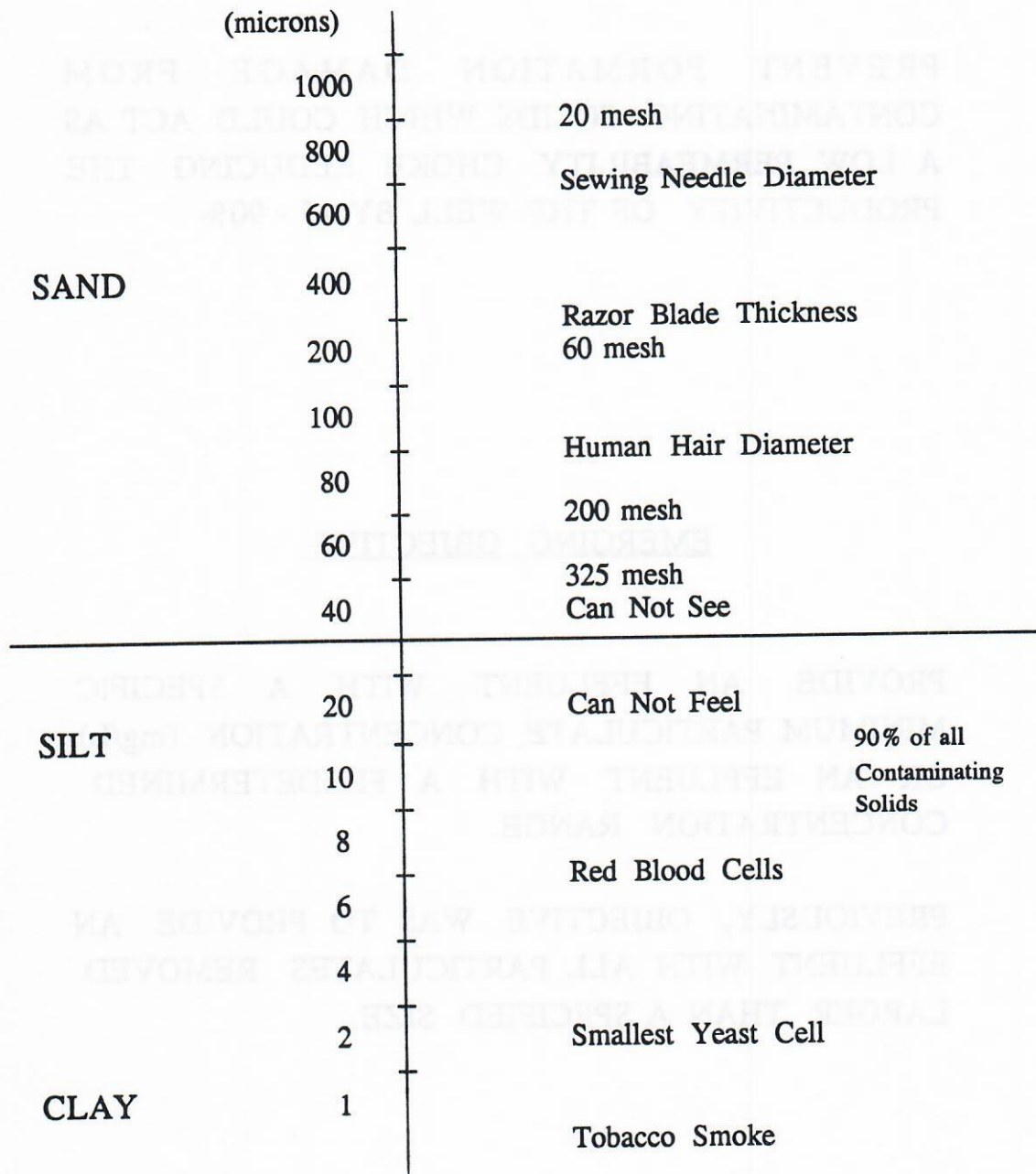
PREVENT FORMATION DAMAGE FROM CONTAMINATING SOLIDS WHICH COULD ACT AS A LOW PERMEABILITY CHOKE REDUCING THE PRODUCTIVITY OF THE WELL BY 15 - 90%

EMERGING OBJECTIVE

PROVIDE AN EFFLUENT WITH A SPECIFIC MINIMUM PARTICULATE CONCENTRATION (mg/L) OR AN EFFLUENT WITH A PREDETERMINED CONCENTRATION RANGE.

PREVIOUSLY, OBJECTIVE WAS TO PROVIDE AN EFFLUENT WITH ALL PARTICULATES REMOVED LARGER THAN A SPECIFIED SIZE.

RELATIVE SIZE OF PARTICLES



PARTICLE SIZE DISTRIBUTION

REGARDLESS OF CONCENTRATION, REMAINING PARTICLES
IN THE EFFLUENT TEND TO HAVE A PARTICLE SIZE
DISTRIBUTION WITH THE LARGEST PARTICLE
EXCEEDING THE MAXIMUM SIZE SPECIFICATION

PARTICLE CONCENTRATION

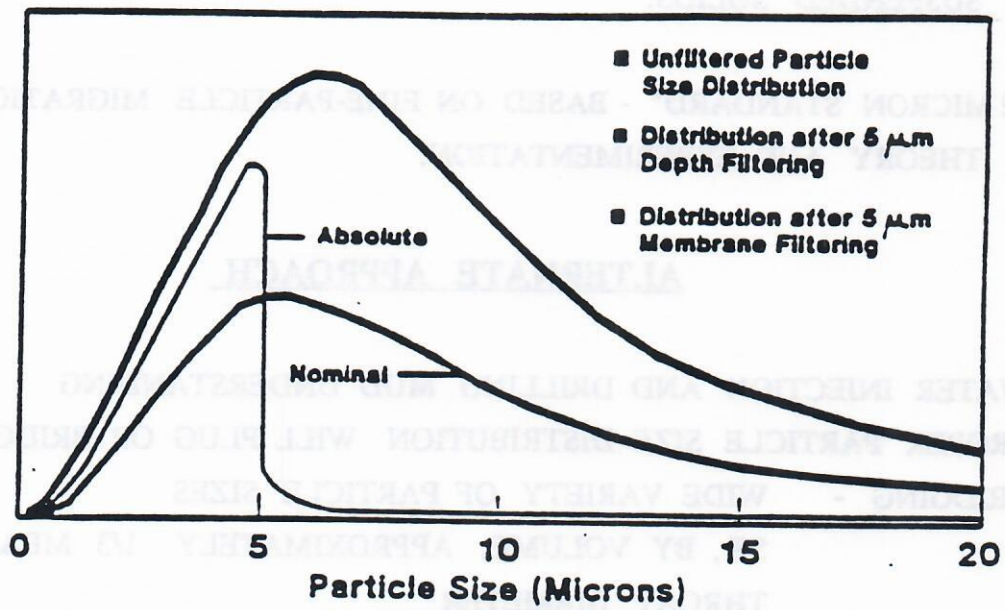
PARTICLE CONCENTRATION TENDS TO DECREASE WITH
A DECREASE IN SPECIFIED LARGEST REMAINING
PARTICULATES IN THE EFFLUENT

FILTRATION TERMS

- ABSOLUTE - A DEGREE OF FILTRATION THAT GUARANTEES 100% REMOVAL OF SUSPENDED SOLIDS OVER A SPECIFIC PARTICLE SIZE.
- ABSOLUTE RATED - SIZE OF LARGEST HARD SPHERICAL PARTICLE THAT WILL PASS THROUGH CARTRIDGE AT SPECIFIC TEST CONDITIONS.
- NOMINAL RATES - ARBITRARY VALUE ASSIGNED TO CARTRIDGE BY MANUFACTURER BECAUSE OF LACK OF REPRODUCIBILITY.

DEPTH vs MEMBRANE FILTRATION

Particle Count



INDUSTRY STANDARDS FOR BRINE CLEANLINESS

"2 MICRON STANDARD" - REDEFINED AS TO A STANDARD OF CLARITY & CONTAMINATION.

"2 MICRON STANDARD" - NO DIRECT CORRELATION TO QUANTITY OF SUSPENDED SOLIDS.

"2 MICRON STANDARD" - BASED ON FINE-PARTICLE MIGRATION THEORY AND EXPERIMENTATION.

ALTERNATE APPROACH

WATER INJECTION AND DRILLING MUD UNDERSTANDING
PROPER PARTICLE SIZE DISTRIBUTION WILL PLUG OR BRIDGE
BRIDGING - WIDE VARIETY OF PARTICLE SIZES
5%, BY VOLUME, APPROXIMATELY 1/3 MEAN PORE
THROAT DIAMETER

CRITERIA:

HIGH DEGREE OF CLARITY (DO NOT CONFUSE WITH COLOR)

LACK OF VISIBLE PARTICLES

LESS THAN 1,000 ppm (0.1% BY VOLUME) SUSPENDED SOLIDS

CORE PLUGGING STUDY

$K_{air} = 100 \text{ md}$

FLOODED WITH 2% KCl SOLUTION (pH 7 TO 8)
CONTAINS - 30 MG/L
OF SILICA FINES

PARTICLE SIZE DISTRIBUTION
0.5 TO 10.0 MICRON

PRESSURE DIFFERENTIAL	-	20 psi
TEMPERATURE OF BATH	-	150°F (66°C)
BASE PERMEABILITY	-	31 md
POROSITY	-	21%
MEAN PORE SIZE	-	8 MICRON

SLURRIES EVALUATED

UNFILTERED
10 MICRON FILTERED
2 MICRON FILTERED
0.5 MICRON FILTERED

REDUCTION IN PERMEABILITY

UNFILTERED	-	GREATER THAN 50% PLUS FILTERCAKE SEEN
10 MICRON	-	REDUCED LOSSES FROM 50% TO 24%
2 MICRON	-	REDUCED LOSSES TO 8%
0.5 MICRON	-	MAXIMUM PROTECTION

PARTICLE PLUGGING BY CLEAN FLUID

BASE FLUID
BAY, RIVER, SEAWATER

SACKED SALTS

PARTICLE MATTER
PITS AND TUBULARS
RUST
SCALE
DOPE
MUDCAKE

IRON OXIDE PRECIPITATE

PRACTICES THAT ENHANCE PRODUCTION

CASING SHOULD BE CLEANED WITH BIT AND SCRAPER OR HYDRAULIC JETS TO FREE MUD SOLIDS, CORROSION PRODUCTS AND OTHER DEPOSITS.

TUBING SHOULD BE SCRAPED AND HYDRAULICALLY CLEANED, INSIDE AND OUT, BEFORE BEING RUN INTO THE WELL.

CREWS SHOULD BE INSTRUCTED TO USE RUNNING PROCEDURES THAT AVOID INTRODUCING EXCESS THREAD SEAL COMPOUND, DIRT AND RIG DEBRIS INTO THE WELL.

FINAL PREPARATION OF A WELL FOR HIGH-DENSITY BRINE COMPLETION OR WORKOVER, INVOLVES CIRCULATING PROGRESSIVELY CLEANER FLUIDS UNTIL SOLIDS HAVE BEEN REDUCED TO ACCEPTABLE LEVELS.

FILTRATION CONSTRAINTS

FILTERING SYSTEM - D.E., CARTRIDGE, BACKFLUSH, ABSOLUTE

PHYSICAL CHARACTERISTICS OF THE FLUID
DENSITY, VISCOSITY, CRYSTALLIZATION POINT

PHYSICAL CHARACTERISTICS OF CONTAMINATING SOLIDS
CLAYS, NONREACTIVE, MICRON SIZE

OPERATOR EXPERIENCE - CLEANER THE FACILITY THE LESS
CONTAMINATION

PHYSICAL CHARACTERISTICS

INCREASE BRINE DENSITY

INCREASE VISCOSITY 1 CP AT 8.5 PPG (1.02 SG) TO A MAXIMUM VISCOSITY OF 58 CP AT 15.1 PPG (1.81 SG) SUMMER BLEND AND 27 CP AT 19.2 PPG (2.30 SG)

REDUCES FLOW RATE & INCREASES SOLID SUSPENSION

SALT COMBINATION AND CONCENTRATION

CRYSTALLIZATION POINT

SALT PRECIPITATION - EFFECTS FILTER LIFE & FLUID DENSITY

SOLIDS CHARACTERISTICS

EFFECTS FILTER CAKE STRUCTURE AND PARTICLE PENETRATION, PARTICLE ADHESIVENESS, SIZE, SIZE DISTRIBUTION, SHAPE, SURFACE CHARACTERISTICS, COMPRESSIBILITY, INTENSITY & POLARITY OF ELECTROSTATIC CHARGES RELATIVE TO THOSE OF FILTER MEDIA.

FILTERING EQUIPMENT

CARTRIDGE

BAG

TUBULAR (BACK FLUSH)

MULTIMEDIA (HIGH RATE)

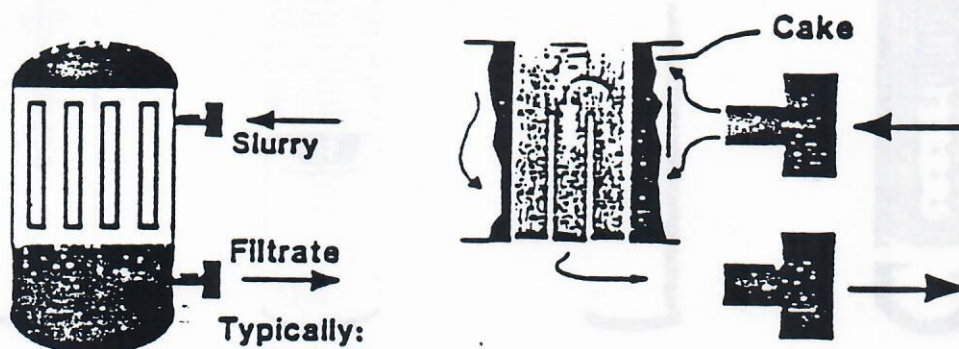
DIATOMACEOUS EARTH

PLATE AND FRAME

PRESSURE LEAF

ABSOLUTE

CARTRIDGE FILTER



Typically:
 18 elements
 2.5 in. Dia. X 30 in. long
 29.5 sq ft
 3 bbl/min

Advantages

Absolute
 Most Common
 Quality
 Low daily rental

Disadvantages

Expensive cartridge
 Slow
 High Maintenance
 Sludge left in pot

STANDARD FILTER ELEMENT TYPES

AVAILABLE FOR

SERIES RFF FILTERS

SERIES 55 FILTERS

SERIES 65 FILTERS

ROLLED LAMINATED
DEPTH TYPE
ELEMENTS



MOLDED FIBER
DEPTH TYPE
ELEMENTS



PLEATED PAPER
SURFACE TYPE
ELEMENTS



PLEATED WIRE SCREEN
STRAINER TYPE
ELEMENTS



PECO FILTER MEDIA SPECIFICATIONS

FILTER-TEX (FT OR FTE) is a blend of cotton and acrylic fiber with wood excelsior added (FTE), of rolled laminated construction designed to achieve fine filtration and large solids storage with engine lube oils and hydrocarbon fluids as well as water solutions having a PH range of 4 - 10. Operating temperatures to 300 degrees F.

MOLDED FIBERGLASS (MG) is a mixture of long staple glass fiber and phenolic resin binder molded into a tubular element designed for fine filtration of water solutions having a PH range of 4 - 10. Temperatures to 400 degrees F.

SISAL (S) is a rolled, laminated element of sisal fiber for coarse filtration. Used for water floods and process cooling water, either fresh or salt water.

PLEATED PAPER (PP) is specially made cellulose paper with either silicon or phenolic resin binder. Provides extended surface for fine filtration of engine lube oils and hydrocarbon solvents and chlorinated hydrocarbons having a PH range of 5 - 9. Temperatures to 275 degrees F.

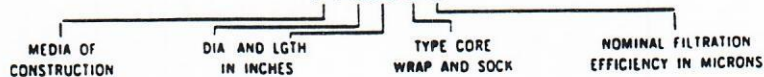
PLEATED WIRE SCREEN (PS) is stainless steel, monel or inconel wire screen. Elements are designed for straining large particles. Can be used as a precoat filter using diatomaceous earth precoat for all fluids.

Element Core Wraps and Outer Socks are either all cotton (C) or all synthetic material (O).

Standard Element Cores are lock-seam machine formed of heavy gauge steel and designed to withstand 55 PSI differential pressure.

PECO ELEMENT NUMBER NOMENCLATURE

FT-336-0-5



PHOTOGRAPHS OF FILTER MEDIA TAKEN WITH A
SCANNING ELECTRON MICROSCOPE
(AT 500X MAGNIFICATION).

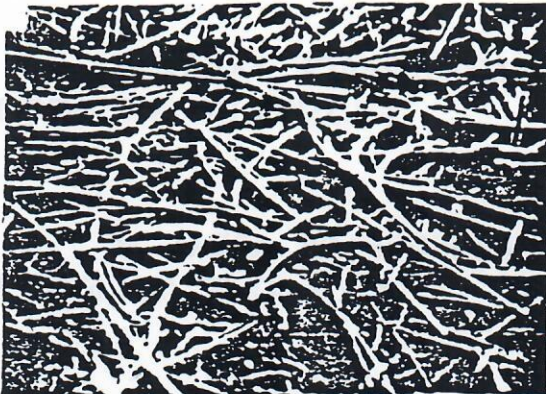


FIG. 1: POROUS MEDIA MICROFIBER MEDIA,
GRADE 03



FIG. 2: POROUS MEDIA MATCHED-PORE PREFILTER

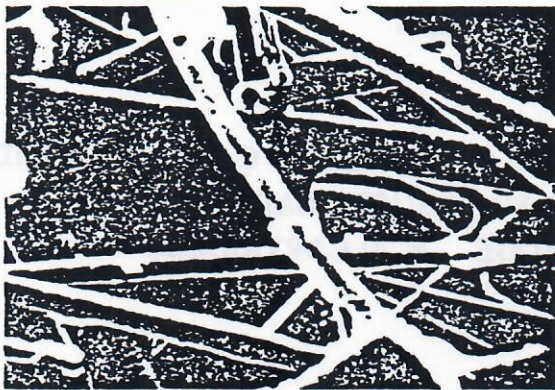


FIG. 3: COARSE GLASS FIBER MEDIA FROM A
CONVENTIONAL FILTER SEPARATOR

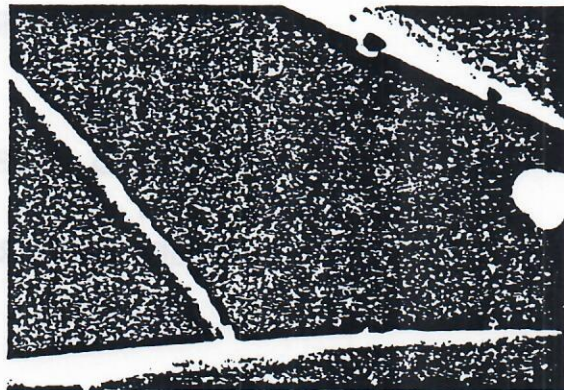


FIG. 4: WIRE MESH MIST ELIMINATOR



FIG. 5: STRING WOUND MEDIA (5um NOMINAL)



FIG. 6: WOUND SOCK MEDIA (5um NOMINAL)

SCALE: 10 20 30 40 50 1mm = 2um

PRICE COMPARISON OF CARTRIDGES

RESIN BOND FILTER (RBF)

$$\begin{aligned} \$ 10.00/\text{FILTER} \div 2.2 \text{ SQ. FT. (.20 SQ M)} (\text{SURFACE AREA}) &= \\ & \$ 4.55/\text{SQ FT.} (\$48.96/\text{SQ M}) \end{aligned}$$

PLEATED CARTRIDGE (40" LONG)

$$\begin{aligned} \$ 30.00/\text{FILTER} \div 22 \text{ SQ FT (2.04 SQ M)} (\text{SURFACE AREA}) &= \\ & \$ 1.36 \text{ SQ FT.} (\$14.63/\text{SQ M}) \end{aligned}$$

DIRT RETENTION

AVERAGE IS 5#/CARTRIDGE

$$\begin{aligned} 1000 \text{ BARRELS OF FLUID WITH } 1000 \text{ ppm SOLIDS} &= 0.35\#/\text{BBL SOLIDS} \\ 0.35\# \times 1000 \text{ BARRELS} &= 350\# \text{ OF SOLIDS}/1000 \text{ BARRELS} \\ 350\# \text{ SOLIDS} \div 5\# \text{ SOLIDS}/\text{CARTRIDGE} &= 70 \text{ CARTRIDGES} \end{aligned}$$

FLOW RATE

$$\begin{aligned} 70 \text{ CARTRIDGES @ } 22 \text{ SQ FT (2.04 SQ M)}/\text{CARTRIDGE} &= \\ 1540 \text{ SQ FT (143 SQ M)} &\text{ OF SURFACE AREA.} \end{aligned}$$

$$\begin{aligned} 1540 \text{ SQ FT (143 SQ M)} \div 10 \text{ VISCOSITY} &= \\ 154 \text{ GALLON (.058 M}^3\text{)} &\text{ PER MIN. FLOW RATE} \end{aligned}$$

REMEMBER: DOUBLE THE SURFACE AREA AND QUADRUPLE
THE CARTRIDGE LIFE OR DIRT RETENTION.

CHARACTERISTICS OF PARTICLES

1. CONCENTRATION
2. SIZE AND SIZE DISTRIBUTION
3. SHAPE
4. SURFACE CHARACTERISTICS
5. ADHESIVENESS
6. HYDROSCOPICITY
7. ELECTROSTATICS
8. CHEMICAL COMPOSITION

PARAMETERS OF THE FILTRATION SYSTEM

1. TYPE OF MEDIA
2. SURFACE AREA
3. PUMP PERFORMANCE CHARACTERISTICS
4. EASE OF REGENERATION
5. FILTER AIDS

ORGANIC COLLOIDS

FLOCCULANTS SHOULD BE ADDED AFTER SALT AND IN SMALL QUANTITIES 0.01%. ABOVE 0.01% TOO MANY NEGATIVE CHARGES OF THE FLOCCULANT ARE PRESENT AND CAUSE PARTICLES TO REPULSE EACH OTHER.

BAG FILTER



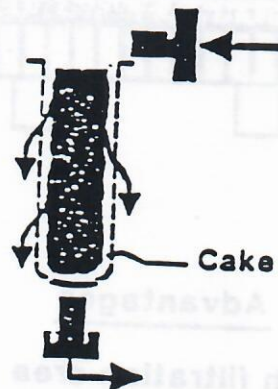
Slurry

Filtrate

Advantages

Fast
Simple
Less Maintenance
Low daily rental

Typically:
5 bags
7 in. Dia. X 32 in. long
22 sq ft
7 bbl/min

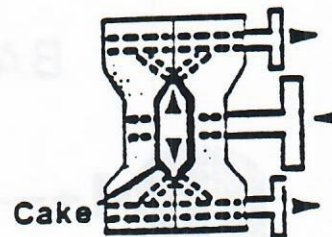
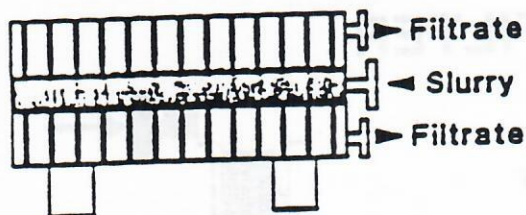


Cake

Disadvantages

Bag Changes
Quality

FILTER PRESS



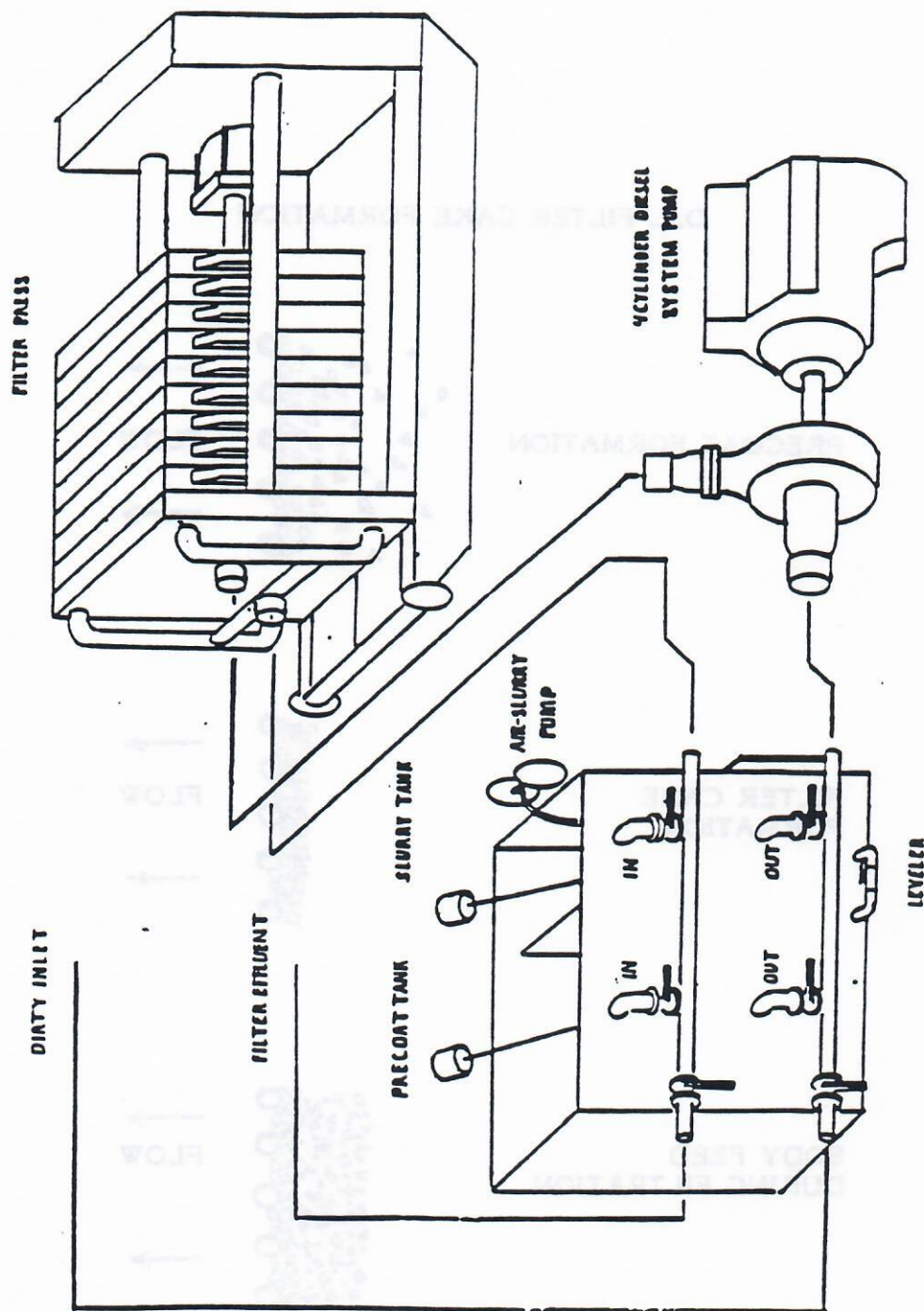
Typically:
 20 plates
 40 in. square
 375 sq ft
 5 bbl/min

Advantages

High filtration area
 Quality
 Reusable filter cloth
 Very forgiving

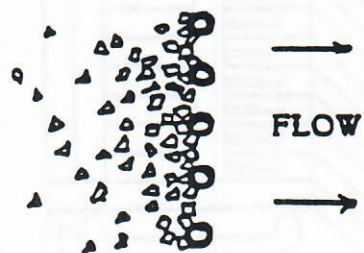
Disadvantages

New & different
 Expensive
 Semi-continuous

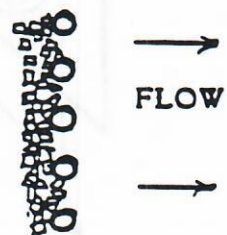


D.E. FILTER CAKE FORMATION

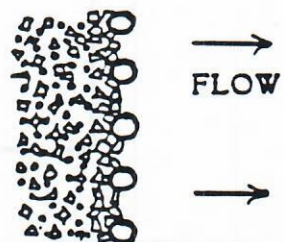
PRECOAT FORMATION



FILTER CAKE FORMATION



BODY FEED DURING FILTRATION



FILTRATION PROCEDURE

- PRECOAT - ESTABLISHING INITIAL FILTER CAKE
- BODY FEED - MAINTAIN CONSISTENT PERMEABILITY IN THE CONTINUALLY GROWING FILTER CAKE.
- BLOWDOWN & CLEANING - REDUCED FLOW RATE & HIGH PRESSURE DIFFERENTIAL ACROSS FILTER
1. BLOW AIR RATHER THAN BRINE THRU FILTER PRESS AND CAKE TO PURGE ALL RESIDUAL BRINE.
 2. RELEASE HYDRAULIC PRESSURE, REMOVE CAKE AND WASH FILTER CLOTH AND FILTER LEAVES.

DIATOMACEOUS EARTH FILTER

98% SOLID REMOVAL EFFICIENCY WITH ONE PASS

AVERAGE SOLID - 74 ppm (ppm 0.007% BY VOLUME)
AND RECORDED AS LOS AS 10 ppm

40% IMPROVEMENT IN SOLIDS REMOVAL EFFICIENCY
OVER CARTRIDGES

17 TIMES CLEANER AFTER ONE PASS

CARTRIDGE FILTER

LESS THAN 60% SOLIDS REMOVAL EFFICIENCY

AVERAGE SOLIDS - ± 1300 ppm AFTER ONE PASS

3.9 ADDITIONAL PASSES TO ATTAIN SOLIDS REMOVAL AND
CLEANLINESS OF ONE PASS WITH D. E. FILTER

FILTRATION RATIO (BETA) VS. REMOVAL EFFICIENCY

<u>BETA (β)</u>	<u>REMOVAL EFFICIENCY (%)</u>
1	0.00
2	50.00
4	75.00
5	80.00
10	90.00
20	95.00
50	98.00
75	98.67
100	99.00
1,000	99.90
10,000	99.99
(Pure)	100.00

$$\beta = 75 = \frac{75 \text{ INLET PARTICLES}}{1 \text{ OUTLET PARTICLE}}$$

$$\frac{75-1}{75} \times 100 = 98.67\%$$

FLOW DENSITY

$$\text{FLOW DENSITY} = \frac{\text{GPM}}{\text{FT}^2} \times \text{VISCOSITY IN CENTIPOISE}$$

MODIFIED DARCY EQUATION

$$\frac{\text{VOLUME}}{\text{TIME}} = \frac{\text{FILTER AREA} \times \text{PRESSURE}}{\text{FLUID VISCOSITY} \times \text{CAKE THICKNESS} \times \text{SPECIFIC CAKE RESISTANCE}}$$

EXAMPLE:

DESIRE FLOW DENSITY OF 1.0

1.0 FLOW DENSITY

20 CP VISCOSITY

400 GPM

400 FT² FILTER x ICP (H₂O) = 1.0 FLOW DENSITY

400 GPM

400 FT² FILTER x 60 CP

400 GPM

400 X 60 x 1.0 FLOW DENSITY
(24000 FT²)

13.33 GPM

800 FT² x 60 = 1.0 FLOW DENSITY

IT COST 6 TIMES AS MUCH TO FILTER A 15.1 PPG SUMMER BLEND AS
A 15.1 PPG WINTER BLEND BRINE.

FILTRATION FUNDAMENTAL

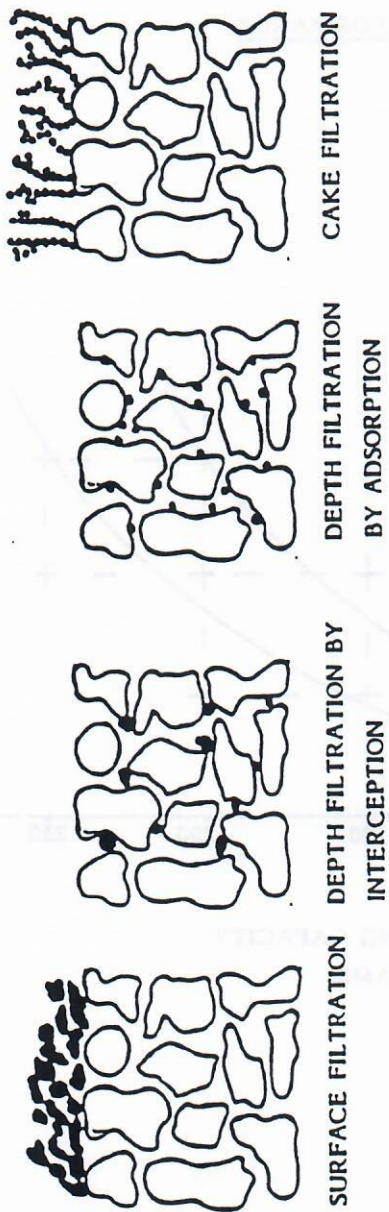
VERY POROUS CAKE - 85-90% PORES

LOW SURFACE AREA

GOOD PARTICLE SIZE DISTRIBUTION

PROPER MICRON SIZE VS. SEPTUM

FOUR BASIC MECHANISMS FOR A POROUS FILTER MEDIUM TO RETAIN PARTICULATES



MECHANISMS OF PARTICLE INTERCEPTION BY FILTER MEDIUM

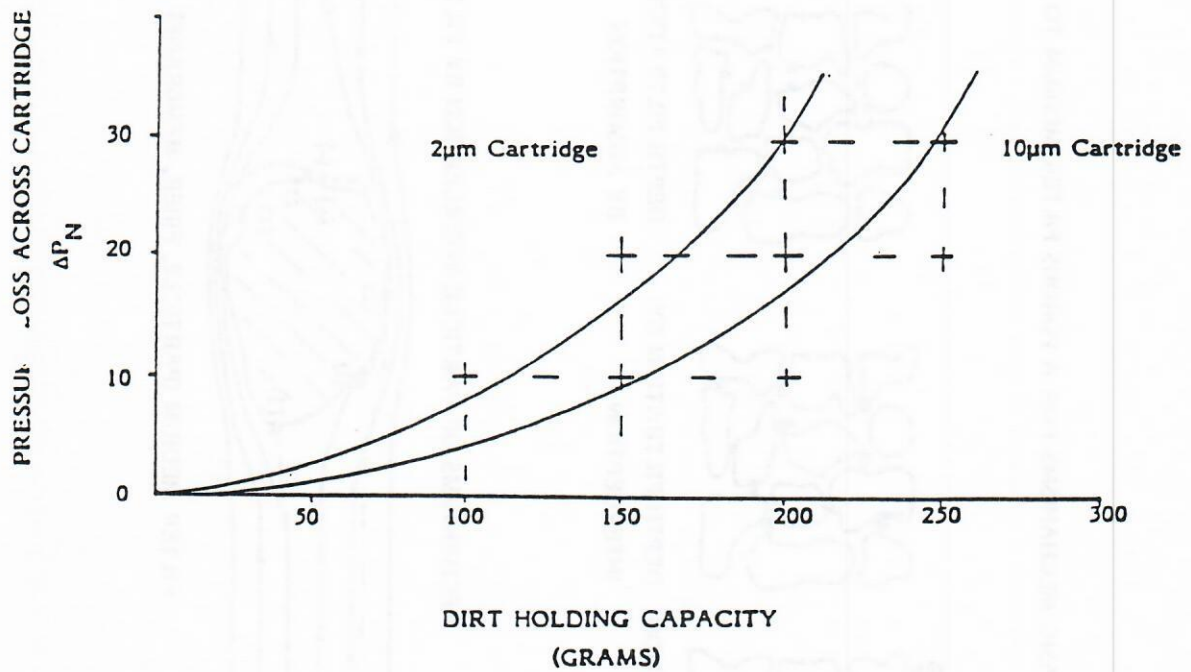
1. DIRECT INTERCEPTION
2. SEDIMENTATION
3. INERTIAL IMPACT
4. BROWNIAN MOTION
5. CHARGE INTERACTION



FILTER MEDIUM (PARTICLE, FIBER, MEMBRANE)

PLEATED FILTER CARTRIDGE

"LIFE" PERFORMANCE



SIZING EQUIPMENT FOR THE JOB

FLOW RATE

SOLIDS LOADING

DENSITY OF FLUID

VISCOSITY

PRECLEANING OF BRINE

PRECLEANING OF RIG FACILITIES

DENSITY VS. FLOW RATE

FLOW RATE OF 10% OR LESS FOR BRINES WITH DENSITIES ABOVE
12.0 PPG (1.44 SG)

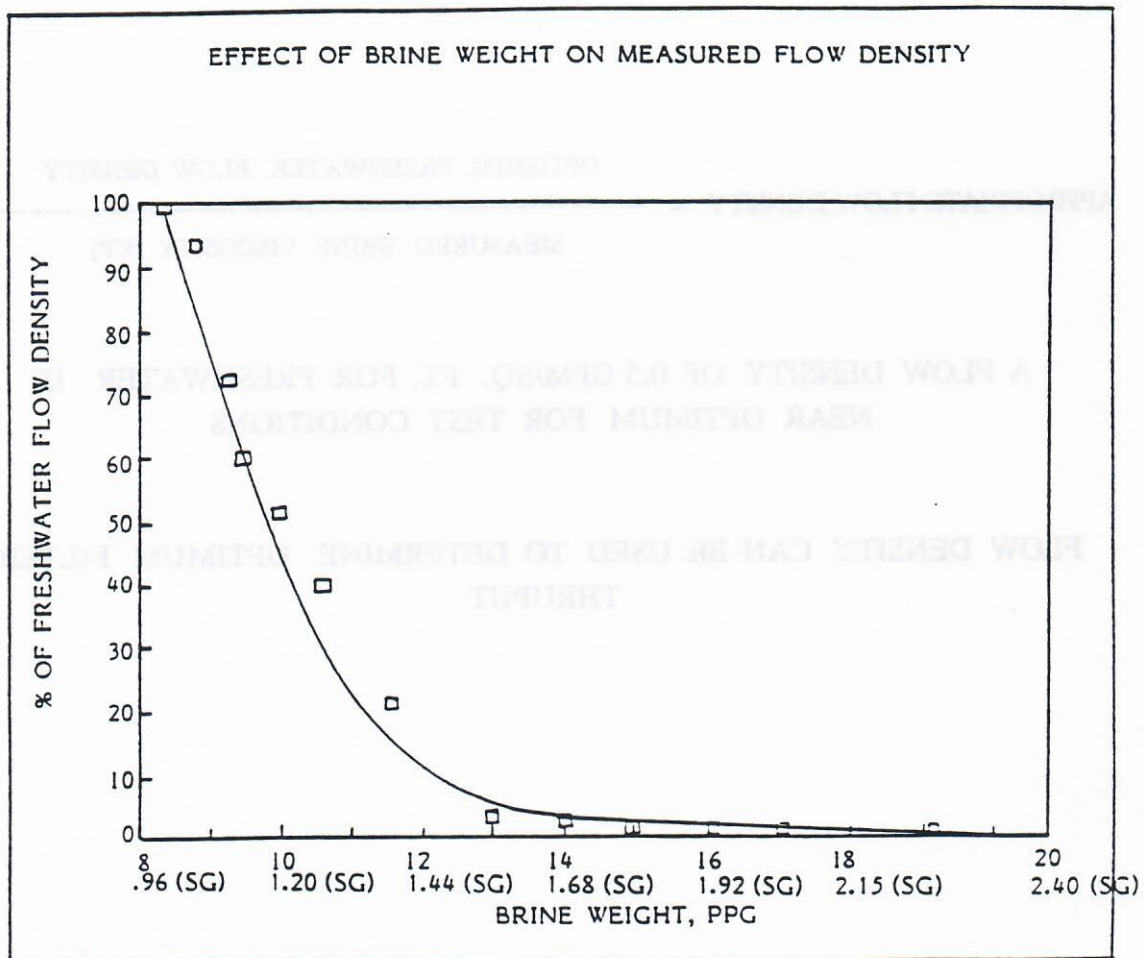
BETTER FLOW DENSITY ACCOMPLISHED BY USE OF
A LARGER FILTER OR LOWER FLOW RATE.

IN THE FIELD

COMPROMISE FILTRATION RESULTS TO MAINTAIN FLOW RATES

OR

COMPROMISE FLOW RATES TO MAINTAIN BRINE QUALITY



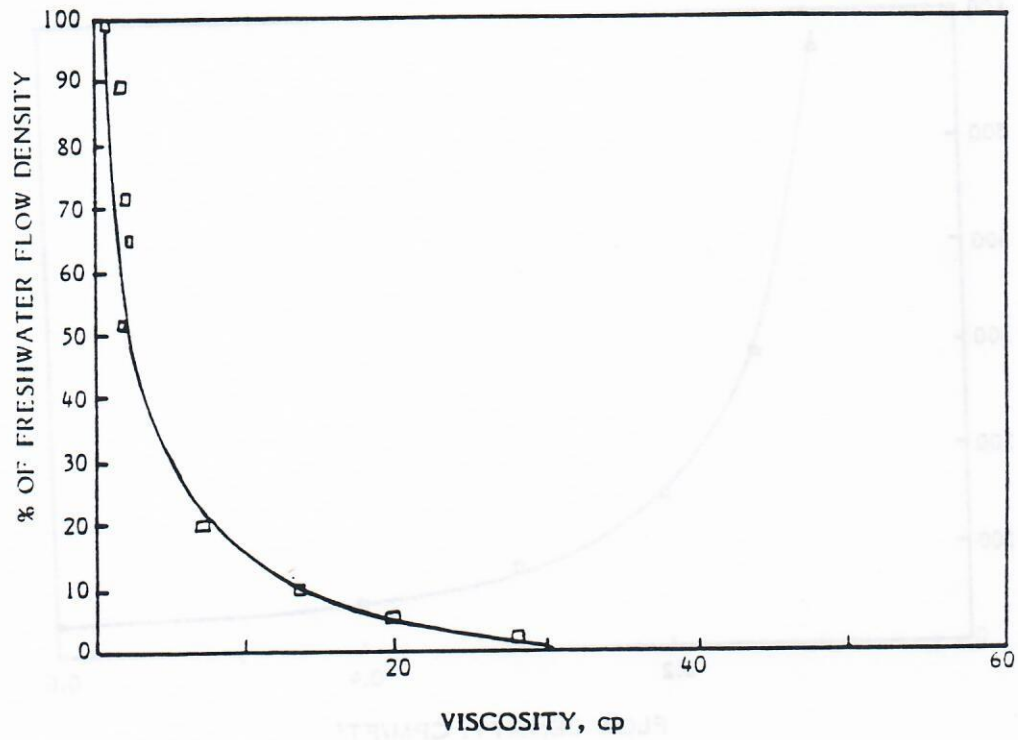
BRINE VISCOSITY AFFECTS OPTIMUM FLOW DENSITY

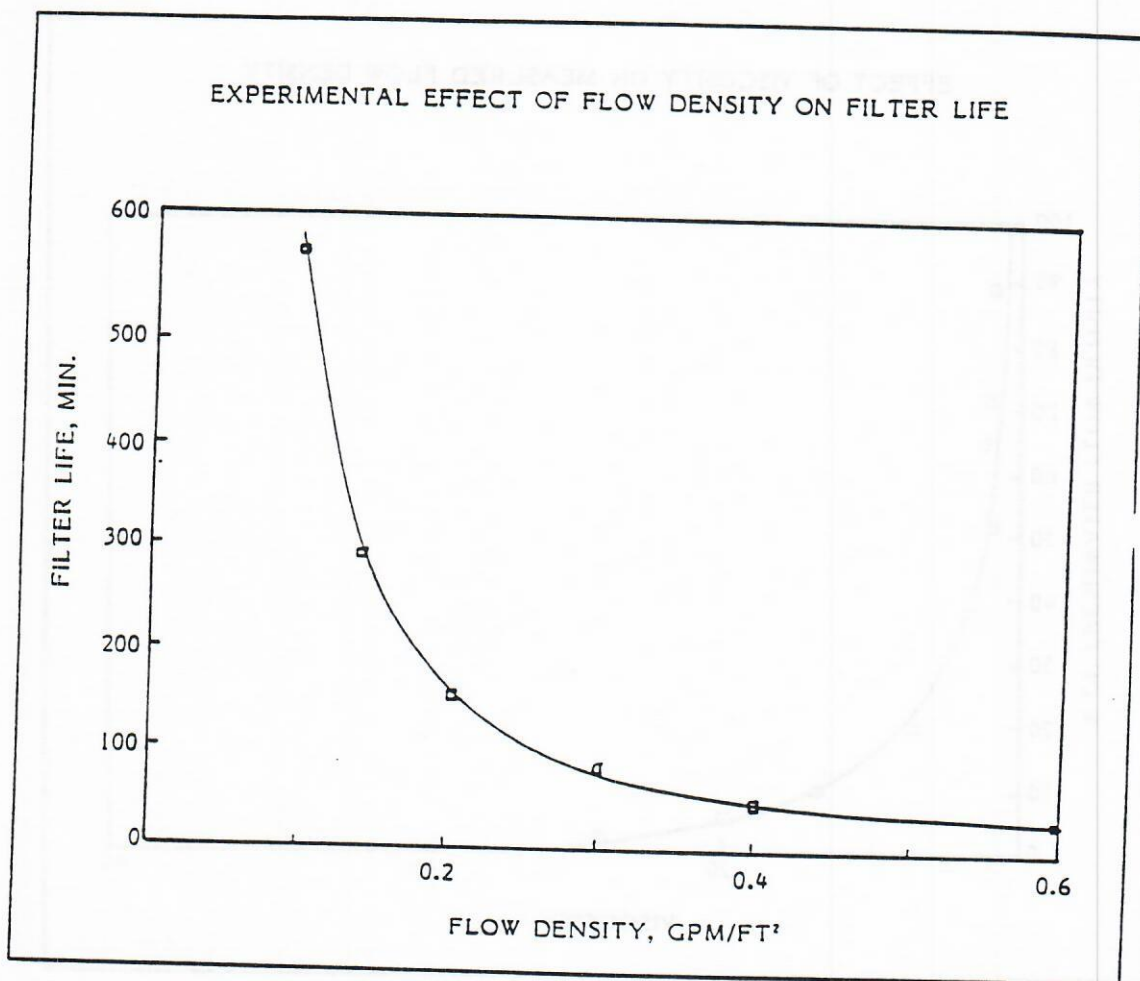
$$\text{APPROPRIATE FLOW DENSITY} = \frac{\text{OPTIMUM FRESHWATER FLOW DENSITY}}{\text{MEASURED BRINE VISCOSITY (CP)}}$$

A FLOW DENSITY OF 0.5 GPM/SQ. FT. FOR FRESHWATER IS
NEAR OPTIMUM FOR TEST CONDITIONS

FLOW DENSITY CAN BE USED TO DETERMINE OPTIMUM FILTER
THRUPUT

EFFECT OF VISCOSITY ON MEASURED FLOW DENSITY

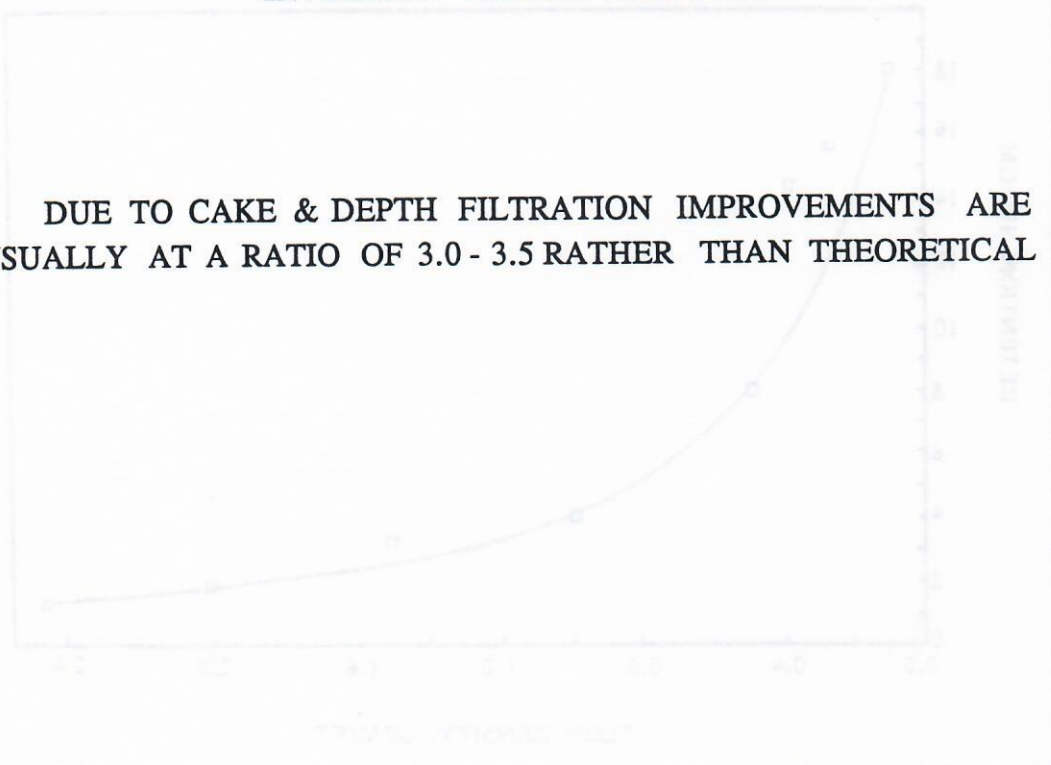


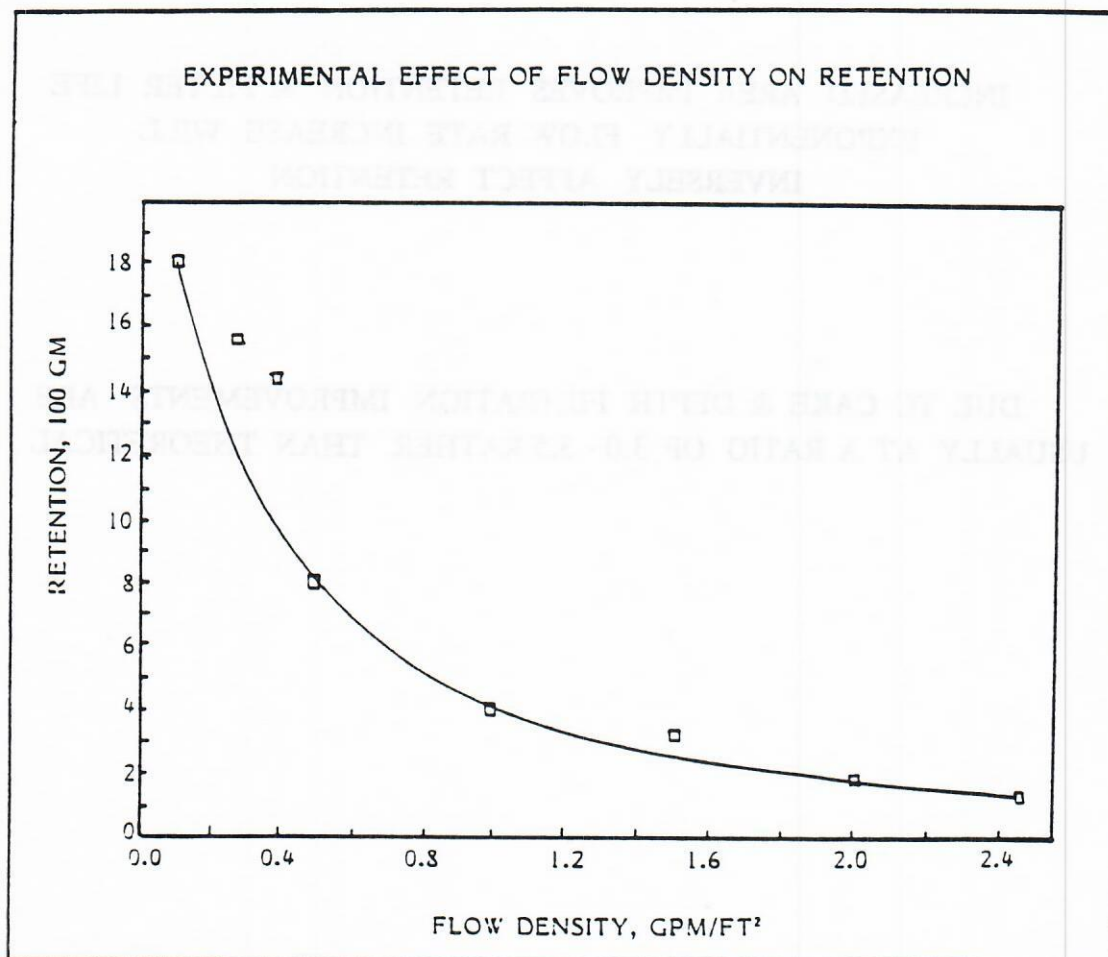


FILTER RETENTION
(TOTAL DIRT RETAINED)

INCREASED AREA IMPROVES RETENTION & FILTER LIFE
EXPONENTIALLY FLOW RATE INCREASE WILL
INVERSELY AFFECT RETENTION

DUE TO CAKE & DEPTH FILTRATION IMPROVEMENTS ARE
USUALLY AT A RATIO OF 3.0 - 3.5 RATHER THAN THEORETICAL 4.0





FILTER EFFICIENCY

PERCENT OF TOTAL SUSPENDED SOLIDS REMOVED BY FILTRATION

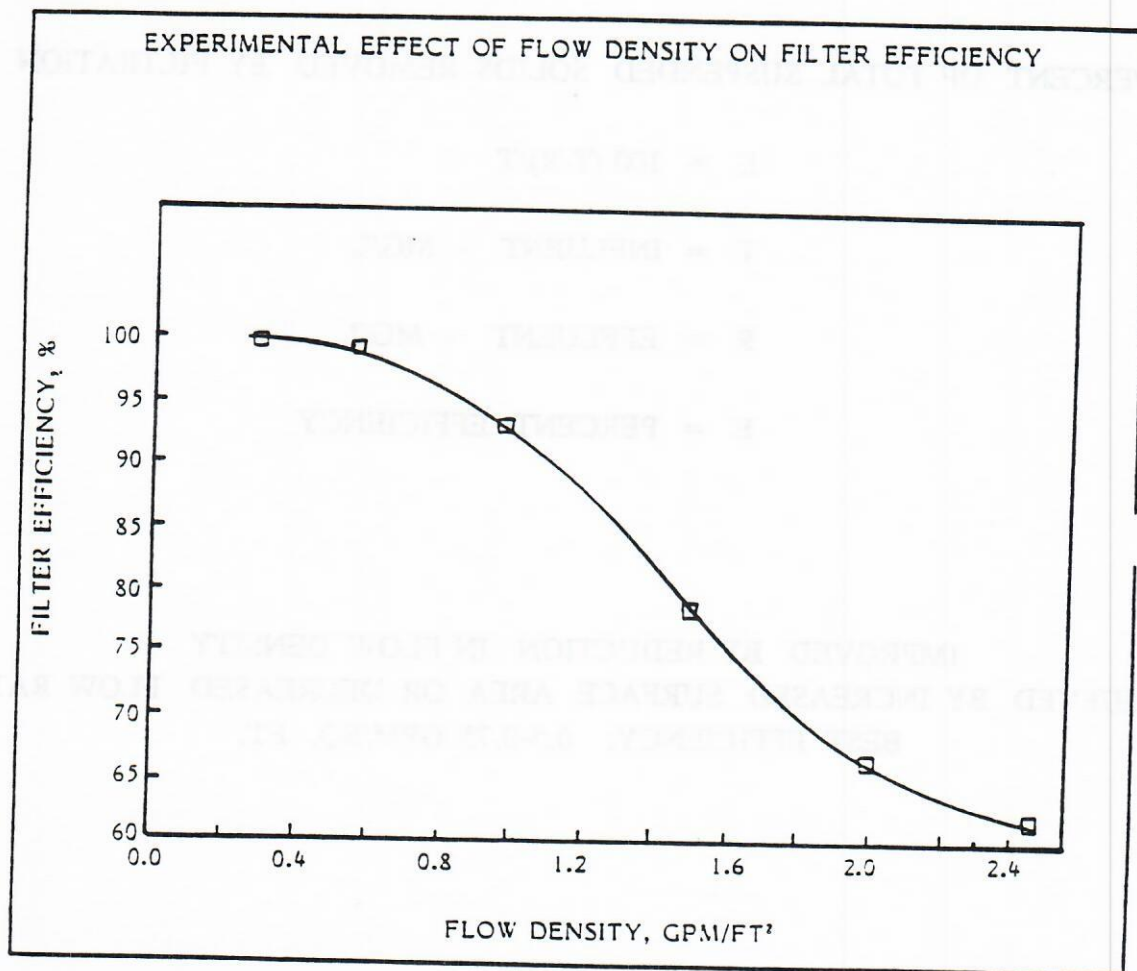
$$E = 100 (T-R)/T$$

T = INFLUENT - MG/L

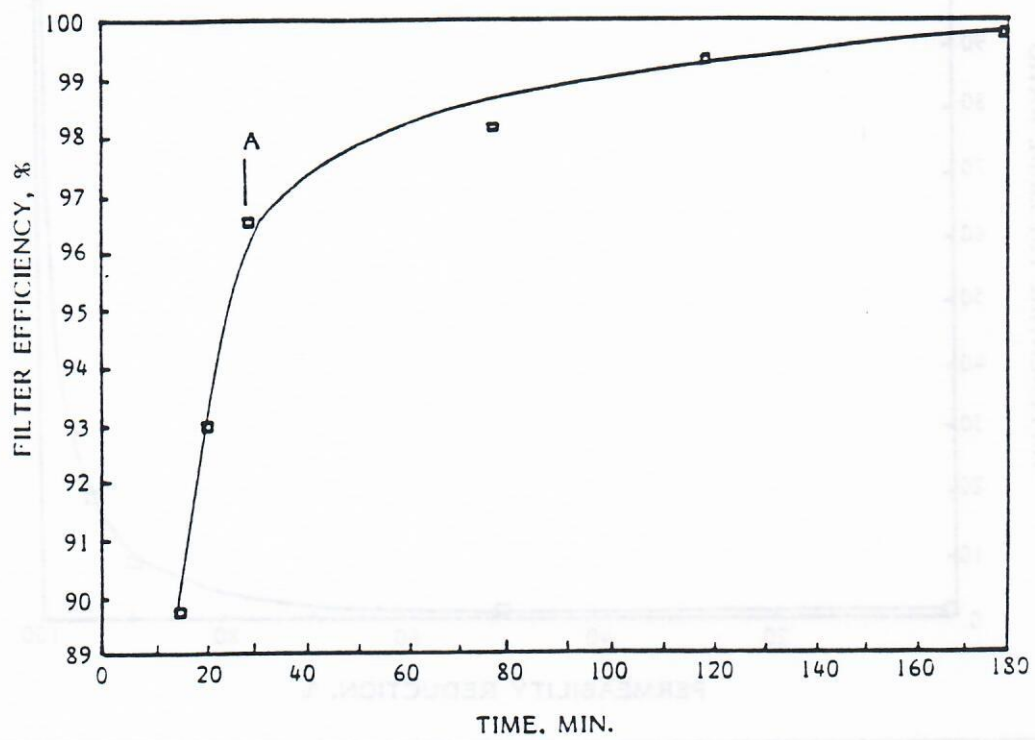
R = EFFLUENT - MG/L

E = PERCENT EFFICIENCY

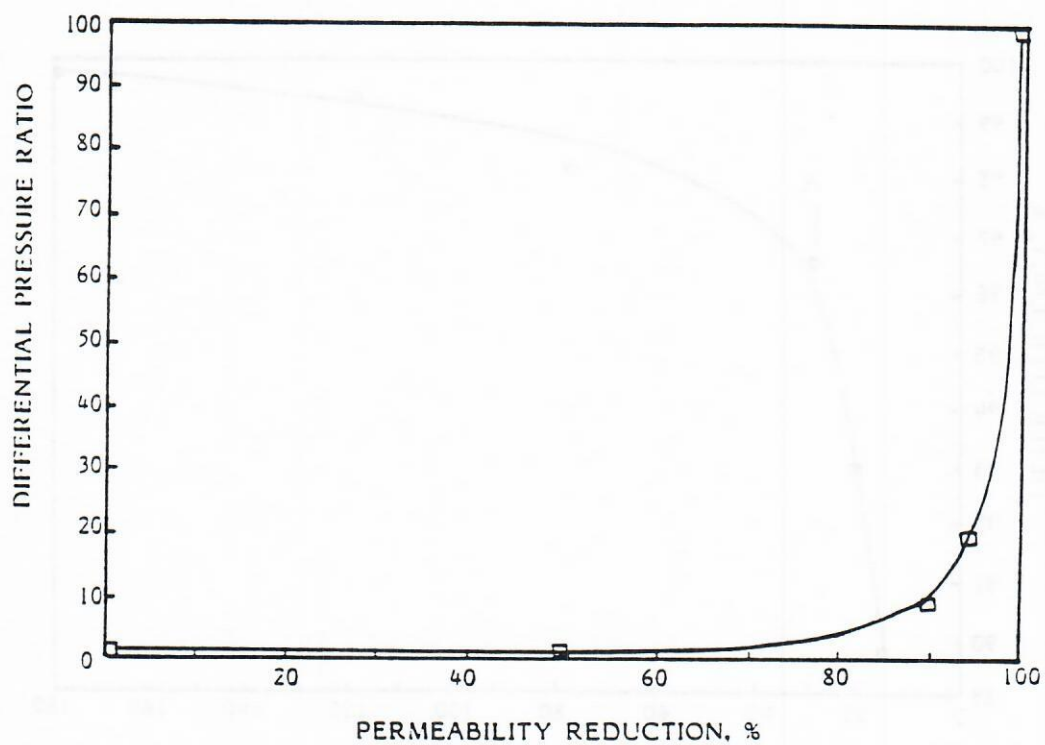
IMPROVED BY REDUCTION IN FLOW DENSITY
ACHIEVED BY INCREASED SURFACE AREA OR DECREASED FLOW RATE
BEST EFFICIENCY: 0.5-0.75 GPM/SQ. FT.



EXPERIMENTAL EFFECT OF TIME ON EFFICIENCY



THEORETICAL EFFECT OF PERMEABILITY REDUCTION
ON DIFFERENTIAL PRESSURE



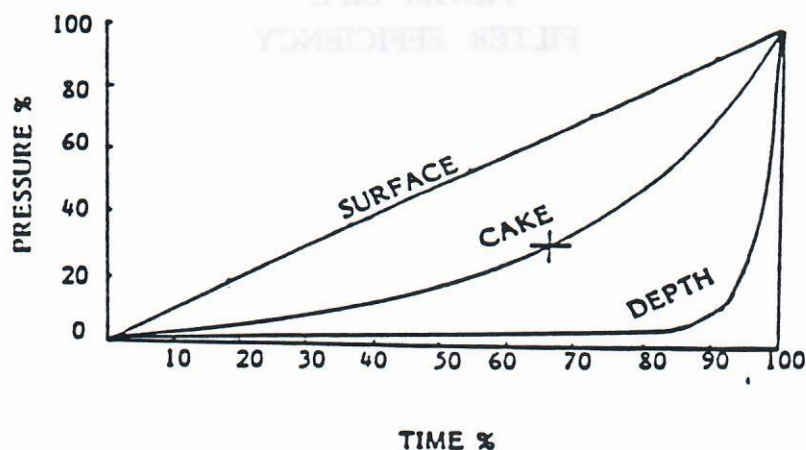
PRESSURE PROFILE

RULE OF THUMB:

1/3 MAXIMUM DIFFERENTIAL PRESSURE IS REACHED AT 2/3 OF FILTER LIFE CYCLE.

40-60 PSI DIFFERENTIAL PRESSURE IS THE COMMON MAXIMUM PRESSURE IN OILFIELD APPLICATIONS.

OPTIMUM FILTRATION PROFILE



IDEAL:

- *START WITH ZERO (0) PRESSURE FOR FILTRATION OTHERWISE WASTE FILTER LIFE.
- *AT 66% OF THE FILTER LIFE CYCLE THE PRESSURE SHOULD BE AT 33% OF TOTAL.

RIG SITE:

START WITH LOWEST ΔP (ΔP) TO PRODUCE ACCEPTABLE FLOW RATE.

FILTRATION

RESULTS & ECONOMICS

IMPROVE BY INCORPORATING THE INTERRELATED EFFECTS
OF VISCOSITY ON FLOW DENSITY

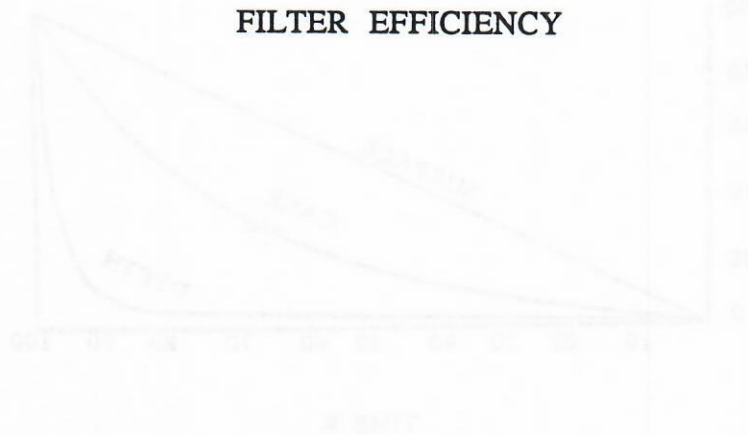
FLOW DENSITY AFFECTS:

FILTER AREA

RETENTION OF SOLIDS

FILTER LIFE

FILTER EFFICIENCY



FILTER LIFE

AFFECTED BY: INITIAL DIFFERENTIAL PRESSURE
IMPROVED BY: REDUCTION IN FLOW DENSITY
ACHIEVED BY: INCREASED FILTER SURFACE AREA
DECREASED FLOW RATE

INITIAL DIFFERENTIAL PRESSURE SHOULD BE AS LOW AS POSSIBLE

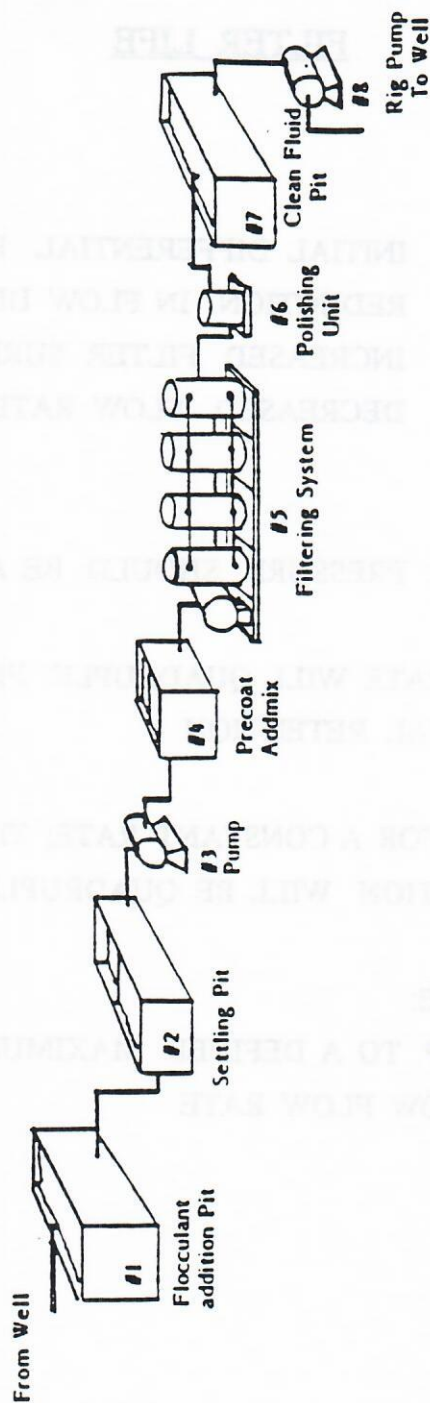
HALVING THE FLOW RATE WILL QUADRUPLE FILTER LIFE, BUT WILL ONLY DOUBLE TOTAL RETENTION

DOUBLE FLOW AREA FOR A CONSTANT RATE; THEN FILTER LIFE AND AND TOTAL RETENTION WILL BE QUADRUPLED

END OF FILTER CYCLE:

PRESSURE BUILDUP TO A DEFINED MAXIMUM
UNACCEPTABLY LOW FLOW RATE

DIATOMACEOUS EARTH - PRESSURE LEAF FILTER SYSTEM



- #1 First Tank - Flocculants are added
- #2 Second Tank - 2 Sections, used for settling of solids
- #3 Pump for precoat and addmix equipment. (D. E. added at this step)
- #4 Tank - 2 sections: Precoat and addmix
- #5 Diatomaceous earth filter cans with screens and pumps (400-600 sq. ft.)
- #6 Polishing filter or guard filter to prevent accidental loss of D. E. downhole
- #7 Tank for clean fluid connected to rig pumps
- #8 Rig pump

FILTER RECOMMENDATIONS

DIATOMACEOUS EARTH UNIT

TYPE:	PLATE AND FRAME
SIZE:	410 SQ. FT. (38.09 SQ M)
PLATE:	1,000 MM
CHAMBERS:	24
CAKE VOLUME:	18.7 CU. FT.
LENGTH:	144 INCHES
WEIGHT:	9,100 LBS.

PRECOAT TANK:

VOLUME:	5 BBLs (.795 M ³)
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BODY FEED TANK

VOLUME:	4 BBLs (.636 M ³)
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AGITATORS

	1/3 HP
--	--------

BODY FEED PUMP

DIAPHRAM	1.7 BBLs./MIN. 100 PSI WITH 30 CFM
ELECTRIC	2.0 BBLs./MIN. 20 HP

GUARD FILTER

BAG	5 4 SQ. FT. EACH (.37 SQ M)
CARTRIDGE	3 16-30 INCH CARTRIDGE EACH
PORE SIZE	5-10 MICRON

HOSES

NEOPRENE	
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COST

NEW	\$ 69,800
REFURBISHED	\$ 40,000

SUMMARY OF FILTRATION TECHNIQUES

Filter type	Micron size limitation	Flow capability	Operating cost*	Comments
(nominal)	1 (nominal)	1-2 bbl/min cartridge bank .159 - .318 m ³	\$5-10/bbl	Cartridges may last less than 15 min. Cartridges must be discarded. Time-consuming to change cartridges. Requires large inventory.
(absolute)	1 (absolute)	1-2 bbl/min cartridge bank .159 - .318 m ³	\$15-50/bbl	Cartridges may last a short time if pretreatment is not done. Bypassing can occur if pressure is not watched closely.
	2 (nominal)	1 bbl/min. pod .159 m ³	\$7-16/bbl	Can develop leaks and tears. Quicker to change than cartridges: Short life.
Multimedia High-Rate	1 (nominal)	As high as 25 bbl/min 3.98 m ³	5¢/bbl	Requires significant amounts of clean fluid for filling and backwashing. Large vessel. Used with injection wells.
Tubular filter (Backwashable)	1-3 (nominal)	0.25-1 bbl/min. tube .04 - .159 m ³	---	Requires backwash recovery unit. Valves can wear quickly.
Plate and frame press with D.E.	<1	6-10 bbl/min. .954 - 1.59 m ³	20¢/bbl	Needs guard filter to protect against accidental D.E. discharge. Large physical system.
Vertical pressure leaf filter with D.E.	<1	1-6 bbl/min .159 - .954 m ³	20¢/bbl	Needs guard filter. Vibration can cause loss of precoat. Overpressurization can damage leaves. Small size.
Tubular filter with D. E.	<1	1-3 bbl/min .159 - .477 m ³	20¢/bbl	Needs guard filter. Short cycle length.

*Expendable materials only

GLOSSARY OF FILTRATION TERMS

Absolute - A degree of filtration that guarantees 100 % removal of suspended solids over a specified particle size.

Absorb - to take up a liquid, like a sponge takes up water.

Activated Carbon - An adsorbent carbon which removes dissolved color, odor and taste, etc. from liquids or gases.

Activated Clay - An adsorbent clay that removes color, odor and free fatty acids, etc. from oils and tallows.

Admix - CELITE that is added directly into the batch tank of prefilter to create a permeable filter, cake. Usually used in place of body feed.

Adsorb - The act of selectively attracting and holding a gas, vapor, liquid or colloid onto the surface of a solid.

Amorphous - Non-Crystalline. Having no ordered molecular structure of its own.

Area - The surface available in a filter for the passage of liquid and formation of a filter cake. Usually measured in square feet.

Atm - Atmosphere. A measure of pressure. The air pressure at sea level; 14.7 psi.

Attrition - Breaking down or wearing away by friction. Usually as particle degradation in a diatomite slurry.

Backwash - A reverse flow of liquid to remove solids from the filter.

Baffle - A plate or deflector to provide flow distribution in a filter. Primary functions are to prevent erosion of precoat and setting of body feed in the filter tank.

Blinding - Plugging or sealing of any portion of a filter septum by solids that are not removed during the normal cleaning cycle.

Blind Spots - Any place on a filter septum where liquid cannot flow through due to blinding.

Blowdown - The use of air or inert gas pressure to displace a liquid out of a filter. Usually through the filter cake. Continued blowdown is used to dry a filter cake in situ.

Body Feed - CELITE that is continuously added to the filter while it is on-stream. Its purpose is to create a permeable filter cake.

Bridging - (1) the act of particles forming an arch over the openings on a septum. (2) Filter cakes that have grown to a size where they actually touch each other in the filter.

Cake - The accumulation of solids (and CELITE) on the surface of the precoat or septum.

Cake Space - The volumetric space available in a filter to support the formation of a cake.

CELITE - Manville's registered trade name for its line of diatomaceous earth filter aids and filters.

Cellulose - A fibrous material of vegetable origin.

Clarity - Clearness of a liquid as measured by a variety of methods.

Cloth - A type of woven filter septum made from natural or synthetic yarns.

Colloid - Very small, insoluble nondiffused solid or liquid particles that remain in suspension in a surrounding liquid. Solids usually on the order of $0.2\mu\text{m}$ or less.

Compressibility - Degree of physical change in suspended solids (or filter cake) when subjected to pressure.

Contact Time - the length of time an adsorbent is in contact with a liquid prior to being removed by the filter.

Cycle - The length of time a filter is "on-stream" before cleaning is needed. Frequently meant to include cleaning time as well.

D'Arcy - A measurement of filter cake permeability expressed by the formula

$$K = \frac{HL}{(1) A P} \quad \text{Named after the French mathematician that first developed the equation.}$$
$$Q$$

D.E. - A commonly used abbreviation for diatomaceous earth.

Deformable - Used to describe suspended solids that extrude into the interstices of a filter cake and cause

rapid filter plugging.

Delta (Δ)P. - A commonly used symbol denoting the pressure drop across a filter.

Density - The weight of a given volume of CELITE or its filter cake. Usually measured in pounds per cubic foot (PCF). Can be measured wet or dry.

Diatomite - An abbreviation of diatomaceous earth.

Diatomaceous Earth - The fossilized skeletons of minute, prehistoric aquatic plants.

Differential Pressure - The difference in pressure between the upstream and downstream sides of a filter or filter cake.

Dissolved Solids - Any solid material that will dissolve in the liquid that is being filtered, such as sugar in water. CELITE filtration does not remove these solids.

Doctor Blade (knife) - A sharp, hard blade that cuts the cake off the surface of a filter. Usually found on rotary vacuum precoat filters.

Effluent - Any liquid that is discharged from a factory, waste treatment facility or filter. Frequently used erroneously to mean filtrate.

Element - Any structural member in a filter on which the septum is supported. May be round, rectangular or cylindrical.

Feed - The mixture of solids and liquid that enters the filter. Synonyms; prefilter influent and incoming slurry.

Filter - Verb - To pass a liquid containing solids through a filter medium whereby the solids and liquid are separated from each other.

Noun - A device for containing the filter media.

Filter Aid - Any material that assists in the separation of solids from liquids. Usually used on difficult filtration applications.

Filter Medium - The permeable material that separates particles from a fluid passing through it.

Filter System - The combination of a filter and associated hardware required for the filtration process.

Filtrate - Any liquid that has passed through the filter media. Sometimes erroneously called effluent.

Filtration - The process by which solid particles are separated from a liquid by passing the liquid through a permeable material.

Filtration Rate - The volume of liquid that passes through a given area of filter in a specific time. Usually expressed as gallons per square foot per minute (or hour).

Flow Rate - The unit rate at which a liquid is passed through a system. Usually expressed in gallons per minute (or hour).

Frazier - A test to measure the air permeability of filter septums. Expressed in c.f.m. or air at P of $\frac{1}{2}$ " W.C.

Friable - Easily crushed or crumbled.

Gelatinous - Used to describe suspended solids that are slimy and deformable, causing rapid filter plugging.

G.S.F.M. - Abbreviation for gallons per square foot per minute. Also, GSFH for hour.

G.P.H. - Abbreviation for gallons per hour.

G.P.M. - Abbreviation for gallons per minute.

Heel - (1) The liquid left in a filter shell at the end of a cycle. (2) The precoat left on a R.V.P.F. at the end of its cycle.

Hydrophilic - Water accepting.

Hydrophobic - Water rejecting.

Interstices - Any void spaces in and around solid particles that are packed together.

Leaf - Any flat filter element that has or supports the filter septum.

Liquor - Material to be filtered - as in "feed liquor".

Manifold - A pipe or assembly into which the filter elements are connected to form one common discharge for the filtrate.

Media (medium) - The material that performs the actual separation of solids from liquids. Sometimes erroneously used to mean septum.

Membrane - Media through which a liquid is passed; usually associated with a very fine or tight type of filtration.

Mesh - (1) Number of strands in a lineal inch of woven filter fabric.
(2) A commonly used synonym for septum, as in wire mesh.

Micron - Now expressed as micrometer (μm). A unit of length; 10^{-6} meters or 39/1,000,000 inches.

Monofilament - A single synthetic fiber of continuous length; used in weaving filter cloths.

Multifilament - A number of continuous fiber strands that are twisted together to form a yarn; used in weaving filter cloths.

Nonwoven - A filter cloth or paper that is formed of synthetic fibers that are randomly oriented in the media. Usually held together with a binder.

On-Stream - Describes when a filter system is producing a filtered product.

Particle Size Distribution - The distribution obtained from a particle count grouped by specific micron sizes.

Permeability - The property of the filter medium that permits a fluid to pass through under the influence of a pressure differential.

pH - Potential Hydrogen. A measurement of the acidity or alkalinity of a substance. A pH of 7.0 is neutral.

Plate - Any flat surfaced filter element. Usually found in horizontal plate filters.

Porosity - The ratio of the void volume to the total bulk volume.

ppm - Parts per million. A unit of concentration: e.g., 3 p.p.m. would be 3 pounds of solids in 1,000,000 pounds of water.

Precoat - The initial layer of CELITE that is deposited on the filter septum. Usually 1/8" thick on pressure filters and 2" to 6" thick on R.V.P.F.

Prefilt - Material to be filtered.

R.V.P.F. - Rotary Vacuum Precoat Filter. A drum filter that is coated with a thick (up to 6" precoat of CELITE.

Scavenger - A filter, or element in the bottom of a filter, that recovers the liquid heel that remains in a filter tank at the end of the cycle.

Screen - A term commonly used for septum.

Septum - Any permeable material that supports the filter media.

Slurry - Any liquid containing suspended solids.

Sp.G - Specific gravity. The weight of any substance relative to the weight of water (water Sp.G - 1.0).

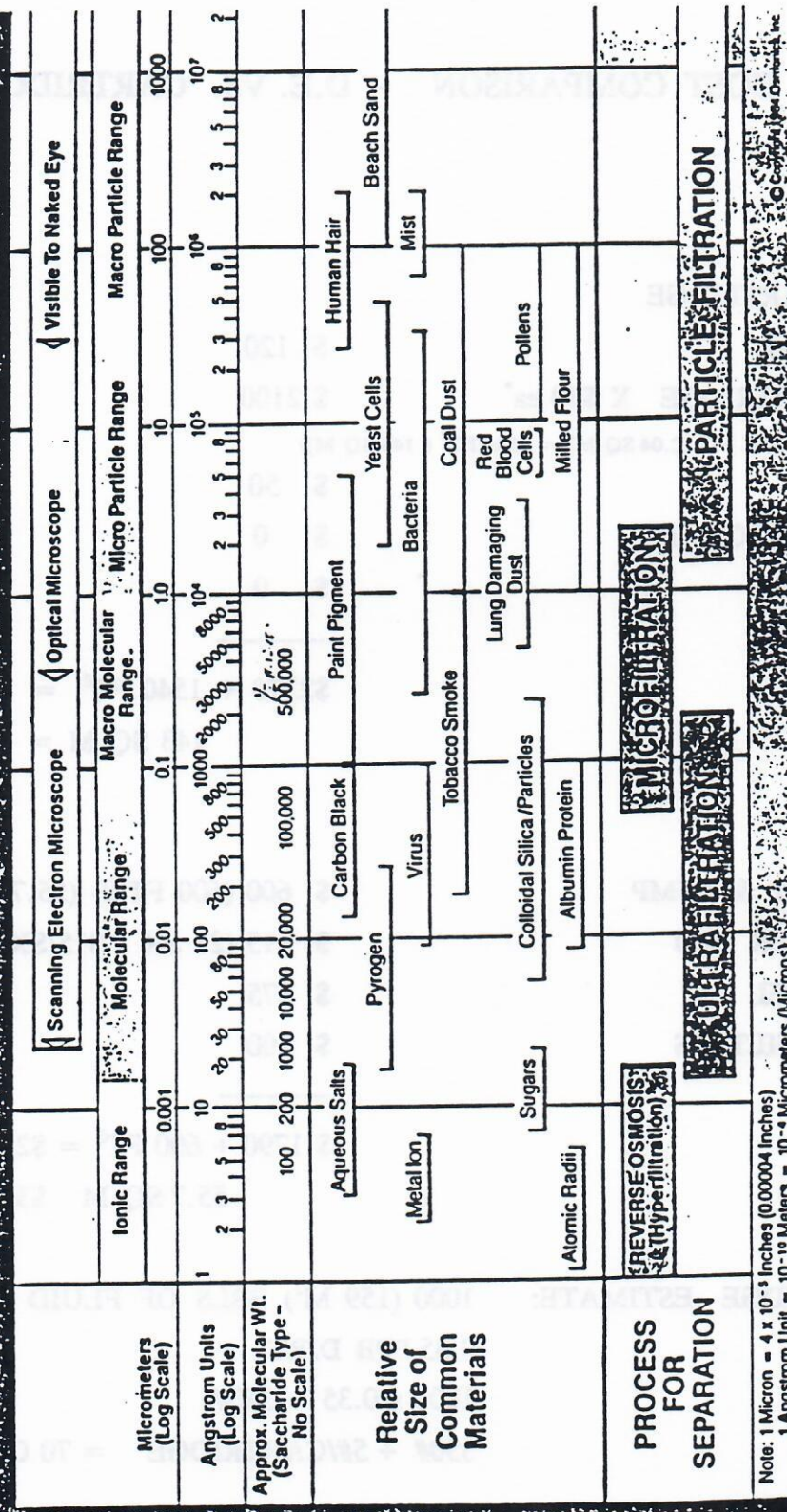
Suspended Solids - (S.S.) - Solids that do not dissolve in liquid; those solids that remain suspended and can be removed by filtration.

Suspension - Any liquid containing undissolved solids, such as a CELITE slurry.

Turbidity - Any insoluble particle that imparts opacity to a liquid.

Voids - the openings or pores in a filter medium.

The Filtration Spectrum



Note: 1 Micron = 4 x 10⁻⁵ Inches (0.00004 Inches)
 1 Angstrom Unit = 10⁻¹⁰ Meters = 10⁻⁴ Micrometers (Microns)

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COST COMPARISON - D.E. VS. CARTRIDGE

2 POT CARTRIDGE

RENTAL \$ 120

70 CARTRIDGE X \$30 ea* \$ 2100

(70 X 22 FT² (2.04 SQ M) = 1540 FT² (143 SQ M))

PUMP \$ 50

NO PERSONNEL \$ 0

HOSES \$ 0

\$2370 + 1540 FT² = \$1.54 FT²

143 SQ M = \$16.57 SQ M

D. E. UNIT & PUMP \$ 600 (600 FT²) (55.7 SQ M)

D.E. FILTER AID \$ 315 (21 SX x \$15/SX)

PERSONNEL \$ 375

GUARD FILTERS \$ 500

\$ 1790 ÷ 600 FT² = \$2.98 FT²

55.7 SQ M \$32.14 SQ M

* CARTRIDGE ESTIMATE: 1000 (159 M³) BBLs OF FLUID = 1000 ppm -
0.35 PPB DIRT
1000 x 0.35 = 350#
350# ÷ 5#/CARTRIDGE = 70 CARTRIDGES

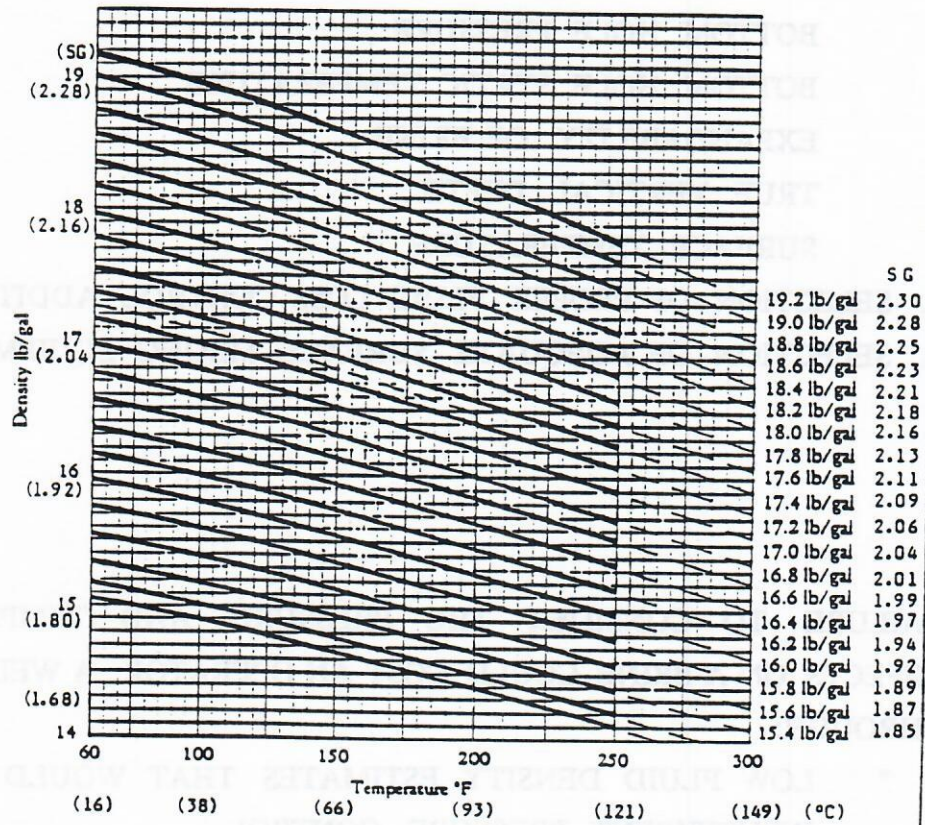
TEMPERATURE AND FLUID LOSS CONTROL PREPLANNING

1. SELECTION OF PROPER BRINE DENSITY BASED ON:
BOTTOM HOLE PRESSURE
BOTTOM HOLE STATIC TEMPERATURE
EXPANDABILITY OF BRINE
TRUE VERTICAL DEPTH
SURFACE TEMPERATURE
2. SELECTION OF PROPER FLUID LOSS CONTROL ADDITIVES
3. SELECTION OF ADEQUATE SURFACE MIXING EQUIPMENT

FAILURE TO CONSIDER THE PRESSURE AND TEMPERATURE EFFECTS ON A BRINE COULD COST AN OPERATOR A WELL EITHER THROUGH:

- ° LOW FLUID DENSITY ESTIMATES THAT WOULD PROVIDE INSUFFICIENT PRESSURE CONTROL.
- ° CONSERVATIVE ESTIMATES THAT WOULD OVER PRESSURE THE FORMATION

EFFECT OF TEMPERATURE ON DENSITY OF BRINES



DENSITY CORRECTION FOR BRINE EXPANSION DUE TO TEMPERATURE

$$\frac{\text{BHST} + \text{Surface Temp.}}{2} = \text{Average Temperature}$$

Example:

$$\frac{260^{\circ} + 80^{\circ}}{2} = 170^{\circ}\text{F}$$

Density Required to Control Downhole Pressure =
Density at 70°F (21°C) + (Avg. Temp. - 70) x Correction Factor

Brine Density Correction Factors

Brine Wt. (lb/gal)	Brine Wt. (SG)	Factors
8.4 - 9.0	1.01 - 1.08	0.0017
9.1 - 11.0	1.09 - 1.32	0.0025
11.1 - 14.5	1.33 - 1.74	0.0033
14.6 - 17.0	1.75 - 2.04	0.0040
17.1 - 19.2	2.05 - 2.30	0.0048

Example:

$$14.0 \text{ lbs/gal} + (170 - 70) \times .0033 = 14.33 \text{ lbs/gal}$$

(1.68 SG) (1.72 SG)

BRIDGING AGENTS

IF A DRILLING FLUID IS ONLY WATER, WATER WILL BE LOST TO THE FORMATION. TO REDUCE LOSSES, SIZED PARTICLES SUCH AS BENTONITE, LIGNITE, LIGNOSULFONATE AND POLYMERS ARE ADDED TO HAVE GRADED MICRON SIZE SPREAD OF PARTICLES IN THE FLUID. THEN AS THE FLUID WITH GOOD GRADING DISTRIBUTION OF SOLIDS IS LOST TO THE FORMATION A CAKE IS FORMED AND LOSS OF WHOLE MUD AND FILTRATE TO THE FORMATION IS REDUCED OR STOPPED.

THE SAME TECHNIQUE IS APPLIED WITH BRINES, SIZED PARTICLES, OVER A LARGE MICRON RANGE, ARE USED TO FORM A CAKE AND PREVENT LOSSES TO THE FORMATION. IN THE CASE OF BRINES, SOLUBLE PARTICLES ARE USED IN AN EFFORT TO PREVENT PERMANENT FORMATION DAMAGE.

FACTORS DETERMINING THE EFFECTIVENESS OF BRIDGING PARTICLES

PARTICLE DISTRIBUTION
PARTICLE CONCENTRATION
PARTICLE SIZE
PARTICLE SHAPE

CALCIUM CARBONATE, OIL SOLUBLE RESIN, GROUND SALT

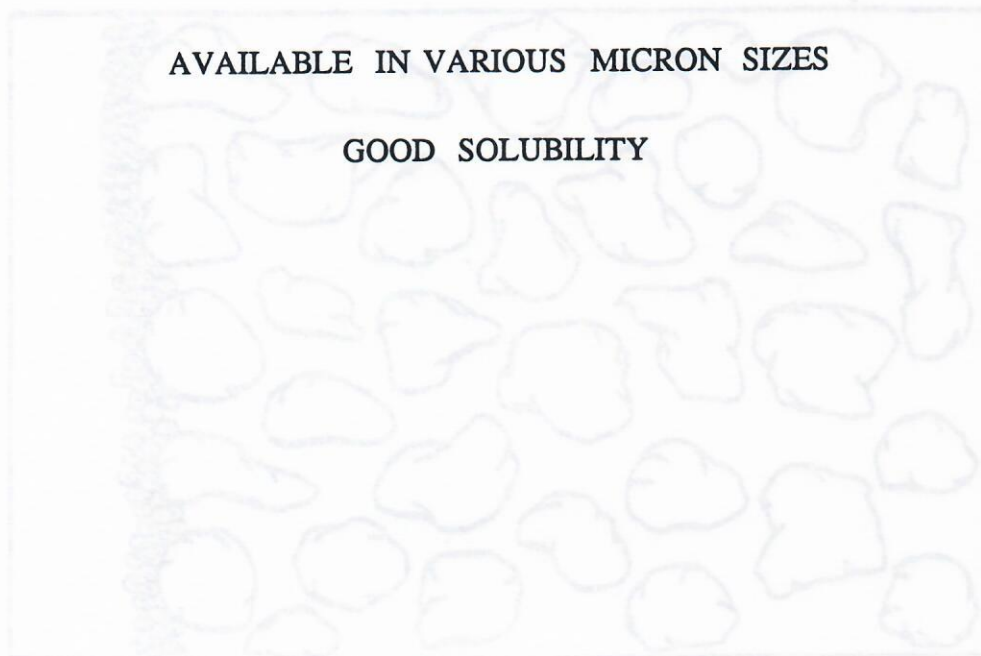
MANUFACTURING CONTROLS

SPECIAL GRINDS

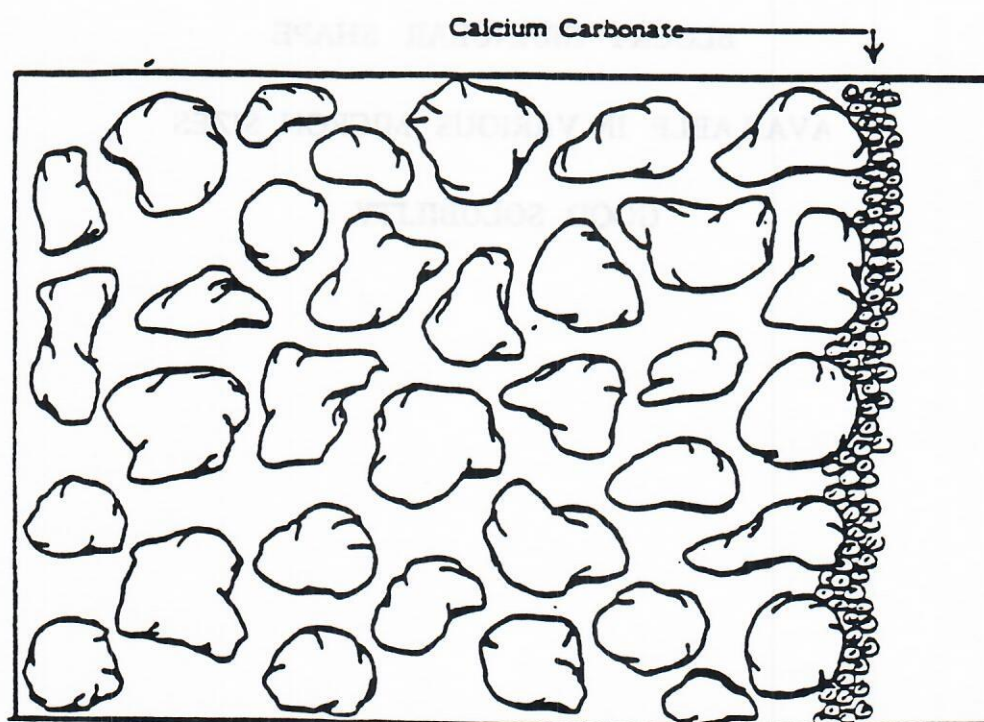
BLOCKY GRANULAR SHAPE

AVAILABLE IN VARIOUS MICRON SIZES

GOOD SOLUBILITY



FLUID LOSS CONTROL ON SURFACE OF FORMATION



RESINS

WAX, SURFACTANT AND ETHYLENE-VINYL COPOLYMER

SOFTEN AT 150° - 200°F (65° - 93°C)

OFFERS FILTRATION CONTROL

THERMOPLASTIC RESINS

SOFTENING POINT 360°F (182°C)

BRIDGING BUT NO FILTRATION CONTROL

PROCEDURE FOR USING RESIN LOST CIRCULATION MATERIAL

MATERIAL IS FRAGILE. ADD FINE, MEDIUM AND COARSE THROUGH HOPPER. HOPPER PUMP SHOULD BE RUN AT A LOW SPEED. GRANULAR SIZE SHOULD BE ADDED THROUGH THE DRILL PIPE OR TUBING. DO NOT CIRCULATE GRANULAR THROUGH PUMP. BREAK KELLY OFF TO ADD.

THE RESIN IS A HIGH MELTING POINT WAX GROUND TO THE PROPER MICRON SIZE. A WATER WETTING SURFACTANT SUCH AS NONIONIC EMULSIFIER, NEEDS TO BE ADDED TO HELP THE RESIN DISPERSE IN THE GELLED PILL.

AS THE PILL REACHES THE ZONE OF INTEREST, INCREASE THE PUMP SPEED TO SQUEEZE THE RESIN INTO THE PERFORATIONS. (EXAMPLE: PUMPING AT 1 BBL. PER MIN. INCREASE TO 2-3 BBL PER MINUTE AS PILL GOES BY ZONE OF INTEREST). CHECK FOR PRESSURE BUILD UP AS THE FORMATION IS SEALED.

ONCE THE ZONE IS SEALED, BLEED THE PRESSURE OFF SLOWLY. THEN CIRCULATE THE REMAINDER OF THE PILL OUT OF THE WELL (JUST AS EXCESS CEMENT WOULD BE CIRCULATED OUT). THE SQUEEZE WILL REMAIN IN PLACE AS LONG AS DIFFERENTIAL PRESSURE REMAINS ON THE FORMATION.

TO REMOVE THE RESIN, SWAB WELL. ALSO THE OIL FROM THE FORMATION WILL BEGIN TO DISSOLVE THE RESIN. THE WELL CAN ALSO BE WASHED WITH DIESEL, XYOLENE OR PARAFFIN SOLVENT.

FLUID LOSS CONTROL AGENT

SIZED CALCIUM CARBONATE

OIL SOLUBLE RESIN

SIZED NaCl CRYSTALS

STARCHES

CLEAN-UP METHOD

ACIDIZE

DIESEL PILL

PRODUCED HYDROCARBONS

AQUEOUS FLUSH

PRODUCED FORMATION
WATER

CHEMICAL "BREAKERS"

WEIGHTING MATERIALS

	ASG.	PPG INCREASE	SG
CALCIUM CARBONATE	2.70	3.5	.42
IRON CARBONATE	3.85	6.5	.78
BARIUM SULFATE	4.43	8.0	.96
FERRIC OXIDE	5.24	10.0	1.20
RESINS	1.04	.7	.08

PERFORATING AND SPACERS USING BA 1005 S AND BA 2000 S

(Calcium Carbonate and Iron Carbonate)
Starting with 9.8 ppg NaCl (1.17 SG)

<u>DENSITY</u>	ppg (SG)	10.5 (1.26)	11.0 (1.32)	12.0 (1.44)	13.0 (1.56)
<u>9.8 NaCl</u>	bbl (M ³)	0.96 (.153)	0.92 (.147)	0.84 (.133)	0.76 (.578)
<u>SODA ASH</u>	ppb	3.0	3.0	3.0	3.0
VS 1000 D	Qt/bbl	1.20	1.10	1.0	.90
BA 1005 S	ppb	38.0	76.0	152.0	227.0
DF 2000 L	ppb	0.01	0.01	0.01	0.01

		<u>50/50</u>	<u>50/50</u>	<u>75/25</u>	<u>100%</u>
<u>DENSITY</u>	ppg (SG)	14.0 (1.68)	15.0 (1.80)	16.0 (1.92)	17.0 (2.04)
<u>9.8 NaCl</u>	ppb	0.75	0.687	0.67	0.66
<u>SODA ASH</u>	ppb	3.0	3.0	3.0	3.0
VS 1000 D	Qt/bbl	1.0	0.75	0.75	0.75
BA 1005 S	ppb	137.0	171.0	98.0	NONE
BA 2000 S	ppb	137.0	171.0	294.0	436.0
DF 2000 L	ppb	0.01	0.01	0.01	0.01

MUD DISPLACEMENT

FRESHWATER, FIELD BRINE, SEAWATER

MULTIPHASE, WEIGHTED SPACER SYSTEM

- I. MUD REMOVAL STAGE
- II. CHEMICAL WASTE STAGE
- III. GELLED SCAVANGER BRINE STAGE

IMPORTANT CONSIDERATIONS

YP OF MUD < YP OF SPACER

CENTRALIZE PIPE IF POSSIBLE

ROTATE AND/OR RECIPRICATE PIPE

REVERSE CIRCULATE

DON'T STOP PUMPING

PUMP PRESSURE - 1100-1300 PSI

PUMP RATE - 2 TO 3 BBLs PER MIN.

SEAWATER DISPLACEMENT

- ° CIRCULATE AND CONDITION MUD
- ° BUILD VISCOUS PILL TO SEPARATE MUD FROM SEAWATER
- ° PUMP SEAWATER
- ° ALTERNATE CAUSTIC PILLS AND VISCOUS SWEEP PILLS UNTIL SWEEP PILLS ARE CLEAN
- ° PUMP VISCOUS BRINE PILL
- ° PUMP BRINE

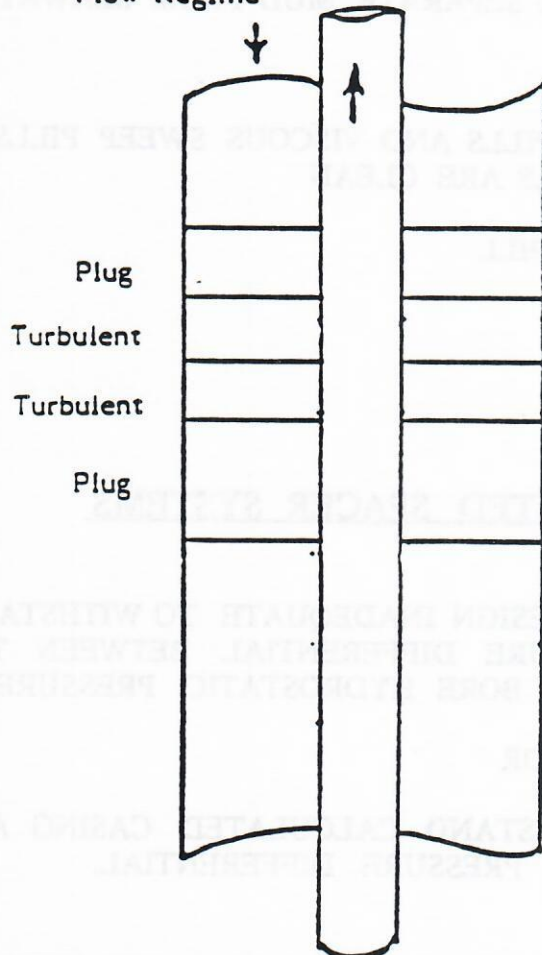
WHEN TO USE WEIGHTED SPACER SYSTEMS

- ° TUBING AND CASING DESIGN INADEQUATE TO WITHSTAND THE EXPECTED PRESSURE DIFFERENTIAL BETWEEN THE RESERVOIR AND WELL BORE HYDROSTATIC PRESSURE.

OR

- ° INADEQUATE TO WITHSTAND CALCULATED CASING AND TUBING HYDROSTATIC PRESSURE DIFFERENTIAL.
- ° IF SQUEEZE WORK HAS BEEN DONE ON THE WELL, A SEAWATER DISPLACEMENT MAY BE EXCLUDED DUE TO THE POSSIBLE LACK OF ADEQUATE CASING INTEGRITY.
- ° NORMAL OR ABNORMALLY PRESSURED WELLS WITH PERFORATIONS EXPOSED.

Flow Regime



Plug

Turbulent

Turbulent

Plug

25 bbl gelled brine
(3.97 m³)

25 bbl gelled water with 5ppg sand
(3.97 m³)

25 bbl 3% caustic wash
(3.97 m³)

50 bbl viscosified and weighted spacer
(7.95 m³)

Pump at 1100-1300 psi
at 2 bbls per min.
(.318 m³)

Direct Displacement Four (4) Pill Spacer

Flow Regime

Pump at 1-2 bbl/min

Plug

Plug

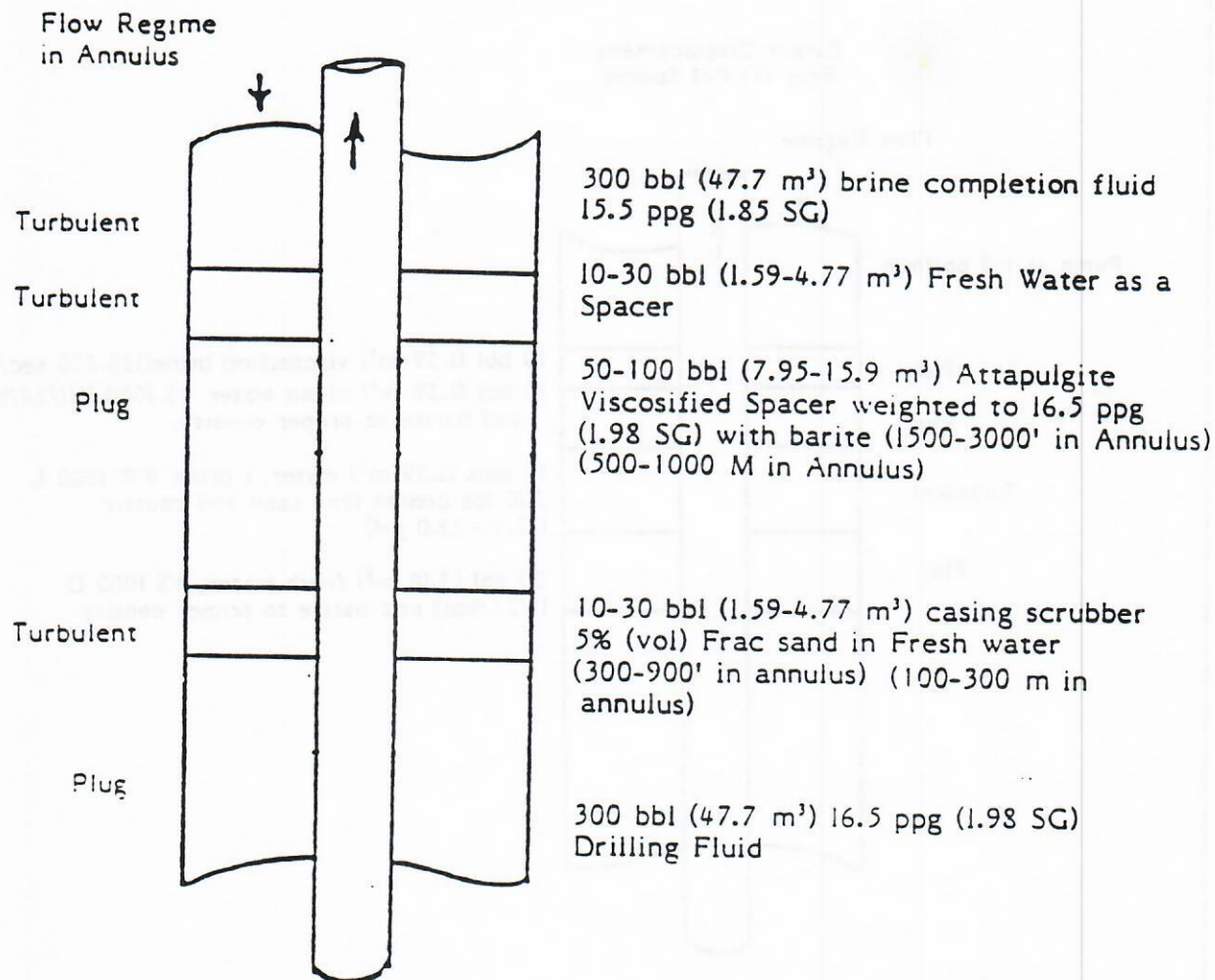
Turbulent

Plug

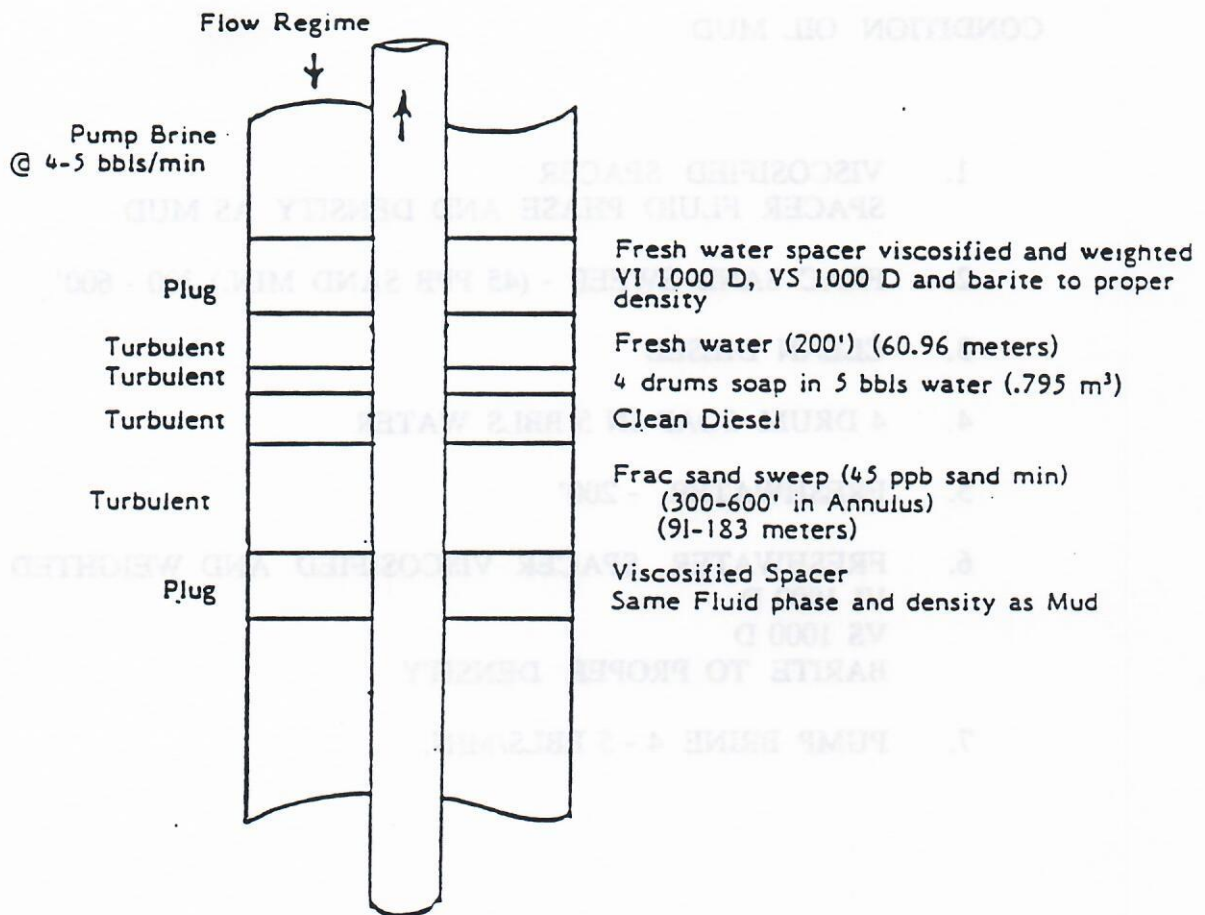
10 bbl (1.59 m³) viscosified brine(150-200 sec/c
10 bbl (1.59 m³) clean water VS 1000 D(1/2#/bb
and barite to proper density.

10 bbls (1.59 m³) water, 1 drum W'W 1000 L.
500 lbs coarse frac sand and caustic
(12.5 - 13.0 pH)

20 bbl (3.18 m³) fresh water, VS 1000 D
(1/2#/bbl) and barite to proper density



Typical Approach to Displacement Spacers for 8000' Well (2,438 meters)



Spacer for Displacing Oil Mud

SPACER FOR OIL MUD DISPLACEMENT

CONDITION OIL MUD

1. VISCOSIFIED SPACER
SPACER FLUID PHASE AND DENSITY AS MUD
2. FRAC SAND SWEEP - (45 PPB SAND MIN.) 300 - 600'
3. CLEAN DIESEL
4. 4 DRUM SOAP IN 5 BBLs WATER
5. FRESHWATER - 200'
6. FRESHWATER SPACER VISCOSIFIED AND WEIGHTED
VI 1000 D
VS 1000 D
BARITE TO PROPER DENSITY
7. PUMP BRINE 4 - 5 BBLs/MIN.

IMPORTANCE OF A CLEAN DISPLACEMENT

KNOWN FACTS

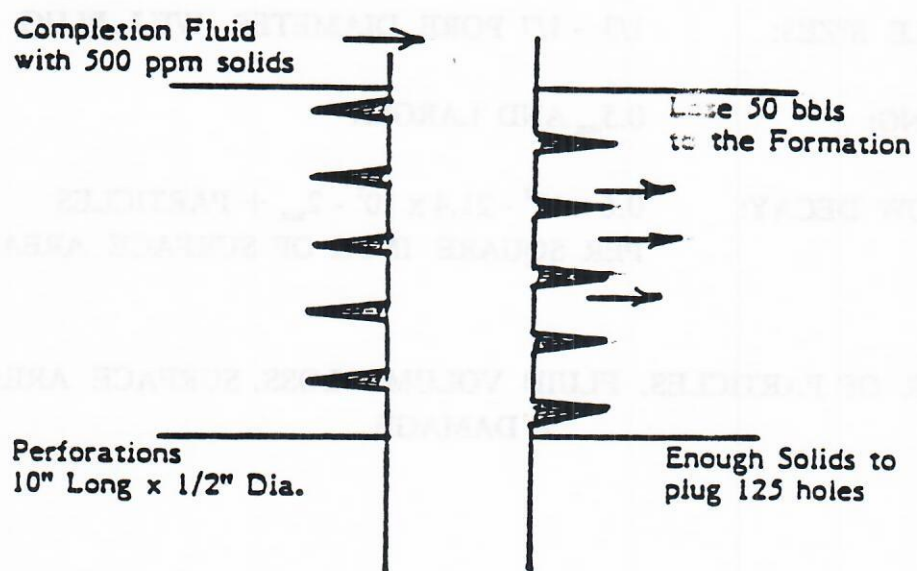
PARTICLE SIZES: $1/3 - 1/7$ PORE DIAMETER WILL PLUG

PLUGGING: $0.5_{\mu\text{m}}$ AND LARGER

50% FLOW DECAY: $0.6 \times 10^7 - 21.4 \times 10^7 - 2_{\mu\text{m}} +$ PARTICLES
PER SQUARE INCH OF SURFACE AREA

NUMBER OF PARTICLES, FLUID VOLUME LOSS, SURFACE AREA =
% DAMAGE

DATA ON CORE PERMEABILITY REDUCTION COMBINED WITH
ACTUAL FIELD DATA ON CONTAMINATION LEVELS CONFIRM 2
MICRON IS CRITICAL TO MINIMIZE FORMATION DAMAGE.



HOW BAD IS SLIGHTLY DIRTY?

ASSUMING 0.5% SOLIDS

50.0 BBL LOSS (7.95 m³)

$$\begin{array}{rcl} (0.005) (50 \text{ BBLs}) (9702 \text{ CU IN/BBL}) & = & 2430 \text{ CUBIC INCHES} \\ (7.95 \text{ m}^3) & (159016 \text{ cu cm}) & (39828 \text{ cu cm}) \end{array}$$

$$\begin{array}{rcl} \text{PERFORATION} & = & 1/2" \times 8" \text{ LONG} & = & 1.5677 \text{ CUBIC INCHES} \\ & & 1.27 \text{ cm} \times 20 \text{ cm} & & 25.69 \text{ cu cm} \end{array}$$

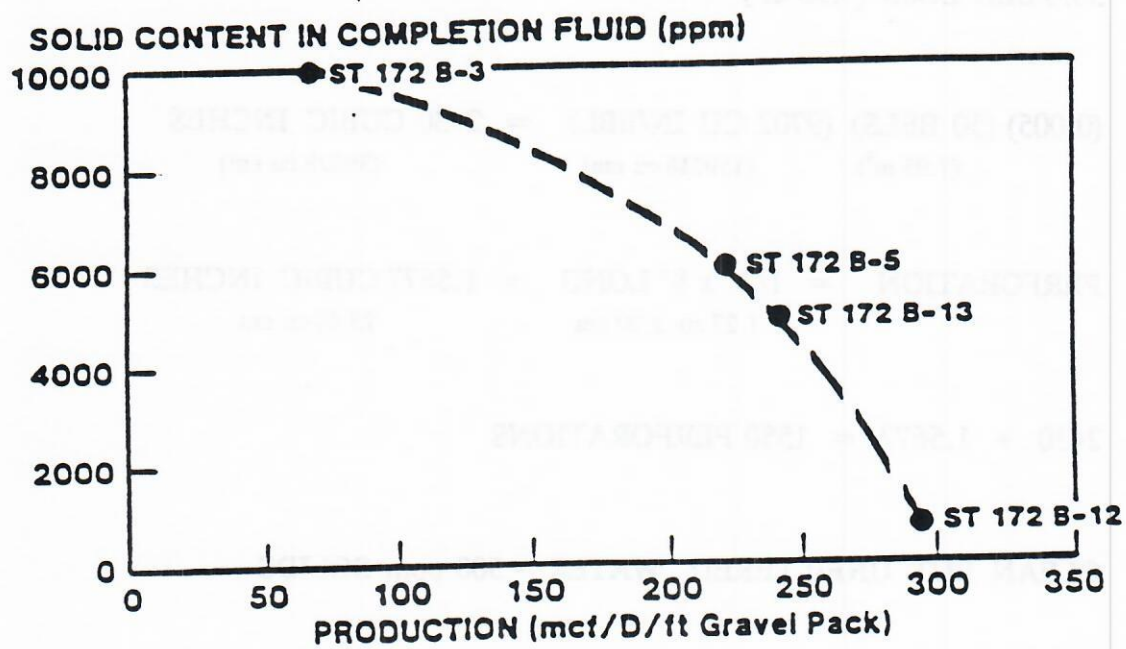
$$2430 \div 1.5677 = 1550 \text{ PERFORATIONS}$$

CLEAN BUT UNFILTERED WATER - 500 ppm SOLIDS

$$0.05\% \text{ SOLIDS} = 1/10 \text{ SOLIDS}$$

PLUG 155 PERFORATIONS

THE EFFECT OF SOLIDS CONTENT IN COMPLETION FLUID ON PRODUCTIVITY



THE PURPOSE OF THE WORKOVER FLUID IS TO CONTROL THE WELL AND PROTECT THE FORMATION FROM DAMAGE DURING THE WORKOVER.

THE MAIN GOAL OF THE WORKOVER IS TO RESTORE OR INCREASE PRODUCTION, NOT TO CAUSE THE WELL TO BE ABANDONED.

SAFETY

SAFETY MEETING

INFORM PERSONNEL

EMERGENCY PROCEDURES

INGESTED

INHALATION

OVER EXPOSURE

SKIN

EYES

EQUIPMENT

FACE SHIELD

EYE GOGGLES

HEAVY RAIN GEAR

RUBBER SAFETY BOOTS

HEAVY DUTY RUBBER GLOVES

HAND LOTION

SAFETY

CALCIUM CHLORIDE, CALCIUM BROMIDE AND ZINC BROMIDE SOLUTIONS ARE STRONG SALT SOLUTIONS - DEHYDRATING ACTION ON TISSUES

AVOID EYE CONTACT AND EXTENSIVE SKIN CONTACT

IN EVENT OF EXPOSURE

EYES - PROMPTLY FLUSH WITH PLENTY OF WATER FOR AT LEAST 15 MINUTES

GET MEDICAL HELP PROMPTLY

SKIN - PROMPTLY REMOVE CONTAMINATED CLOTHING

WASH WITH SOAP AND WATER

WASH CLOTHING BEFORE RE-USE

GET MEDICAL ATTENTION PROMPTLY IF BURNS APPEAR

BRINES CONTAIN HIGH CONCENTRATIONS OF SALTS. THESE FLUIDS ARE HYDROSCOPIC AND WILL DEHYDRATE SKINS, EYES, CLOTHING AND SHOES. THE HIGHER THE CONCENTRATION OF SALT THE MORE RAPID AND SEVERE THE DEHYDRATION.

THE EYES IN PARTICULAR SHOULD BE PROTECTED. AND, IF BRINE DOES ACCIDENTALLY GET INTO EYES THEY SHOULD BE FLUSHED WITH CLEAN WATER FOR AT LEAST 15 MINUTES. IF ZINC BROMIDE GETS IN THE EYES A PHYSICIAN SHOULD EXAMINE THE EYES TO CHECK FOR POSSIBLE DAMAGE.

REPORTABLE SPILL VOLUME

$$\text{BBL} = \frac{5000 \text{ lbs. ZnBr}_2}{A \times B \times C \times D}$$

WHERE

A = DENSITY OF STOCK ZnBr₂/CaBr₂ BRINE
(19.2 lb/gal) (2.30 SG)

B = VOLUME CONVERSION OF GALLONS TO
BARRELS (42 gal/bbl)

C = WEIGHT FRACTION OF ZnBr₂ IN 19.2 lb/gal
STOCK BRINE (0.567); AND

D = VOLUME FRACTION OF 19.2 lb/gal STOCK BRINE
IN BRINE FORMULATION OF INTEREST

$$\text{THUS, REPORTABLE SPILL VOLUME} = \frac{5000}{(19.2) (42) (0.567) D}$$

$$\text{THIS EQUATION MAY BE SIMPLIFIED TO } \frac{10.94}{D}$$

REPORTABLE SPILL EXAMPLE

APPROXIMATELY 25 BBLS (3.98 m³) OF 16.0 lb/gal (1.92 sg) BRINE WAS LOST IN THE GULF DURING FLUID TRANSFER IN ROUGH WEATHER

SHOULD THE EPA BE NOTIFIED OF SPILL?

FROM MIX TABLES, D = 0.22 bbl/bbl

10.94

— = 49.7 bbls (7.90 m³) REPORTABLE SPILL VOLUME

.022

SINCE THE SPILL WAS LESS THAN 49.7 BBLS (7.90 m³), THE SPILL WAS NOT REPORTABLE

LIFE CYCLE OF A BRINE FLUID

CALCULATE BRINE DENSITY AND VOLUME REQUIRED (COMPENSATE FOR EXPANSION DUE TO WELL TEMPERATURE).

MIX BRINE

1. MIX IN CLEAN TANKS
2. TRANSPORT IN CLEAN EQUIPMENT
3. STORE IN CLEAN TANKS AT PLANT AND ON WELLSITE

DISPLACEMENT

1. COORDINATE AND COMMUNICATE PLAN
2. CLEAN RIG LINES, PUMPS AND TANKS
3. PREPARE SPACERS
4. CONDITION FLUID IN HOLE
5. DISPLACE BY REVERSE CIRCULATING
6. ROTATE AND RECIPROCATATE PIPE
7. MONITOR RETURNS. KEEP MUD, SPACERS AND BRINES SEPARATED

CONDITION BRINE IN WELL

1. ADJUST DENSITY
2. FILTER UNTIL PREDETERMINED SPECIFICATIONS FOR CLARITY AND CLEANLINESS ARE MET
3. FILTER WHILE WORKING WITH BRINE IN WELL

DISPLACEMENT OF BRINE FROM WELL

1. SPACER BETWEEN BRINE AND DISPLACING FLUID
2. PUT BRINE IN CLEAN TANKS FOR TRANSPORTATION AND STORAGE

RECONDITIONING BRINE

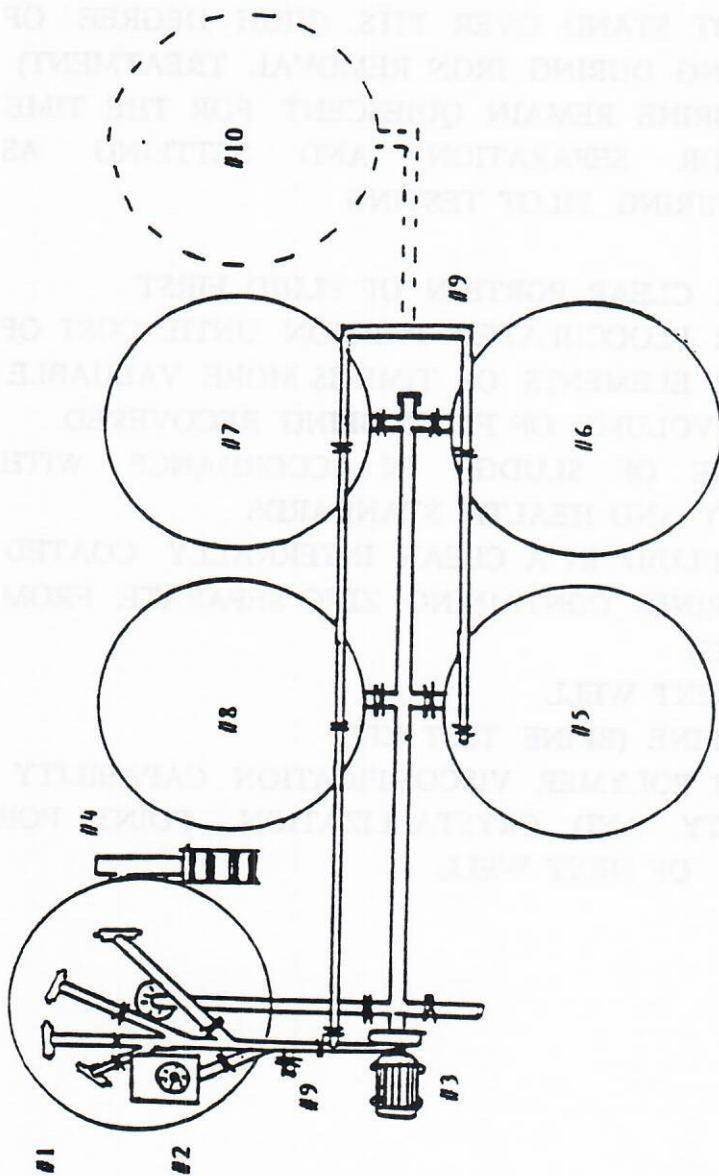
1. PILOT TEST TO DETERMINE TREATMENTS REQUIRED BEFORE FILTERING
 - A. FLOCCULANT FOR CLAY AND FINES
 - B. IRON REMOVAL
 - C. VISCOSITY BREAKER

2. ADD FLOCCULANT, IRON SEQUESTERANT AND/OR BREAKER
 - A. MIX IN THOROUGHLY, BUT NOT WITH VIOLENT AGITATION
 - B. FOR IRON REMOVAL TREATMENT AND VISCOSITY BREAKERS, USE WELL VENTED OR OPEN TANKS. DO NOT STAND OVER PITS. (HIGH DEGREE OF FOAMING DURING IRON REMOVAL TREATMENT)
3. LET TREATED BRINE REMAIN QUIESCENT FOR THE TIME NECESSARY FOR SEPARATION AND SETTLING AS DETERMINED DURING PILOT TESTING
4. FILTER FLUID
 - A. FILTER CLEAR PORTION OF FLUID FIRST
 - B. FILTER FLOCCULATED PORTION UNTIL COST OF FILTER ELEMENTS OR TIME IS MORE VALUABLE THAN VOLUME OF FLUID BEING RECOVERED
 - C. DISPOSE OF SLUDGE IN ACCORDANCE WITH SAFETY AND HEALTH STANDARDS
5. STORE CLEAN FLUID IN A CLEAN INTERNALLY COATED TANK (KEEP BRINES CONTAINING ZINC SEPARATE FROM NONZINC BRINES)

PREPARE FLUID FOR NEXT WELL

1. ANALYSIS OF BRINE (BRINE TEST KIT)
2. PILOT TEST FOR POLYMER VISCOSIFICATION CAPABILITY
3. ADJUST DENSITY AND CRYSTALLIZATION POINT FOR REQUIREMENTS OF NEXT WELL

LIQUID MUD PLANT



Discharge Lines & Fillup Lines

Suction Lines

Mix Tank

Hopper

6" Pump w/671 Diesel or 100 HP Electric Motor

Stairs & Walkways

Mud Storage Tanks

Mud Storage Tanks

Mud Storage tanks

Mud Storage tanks

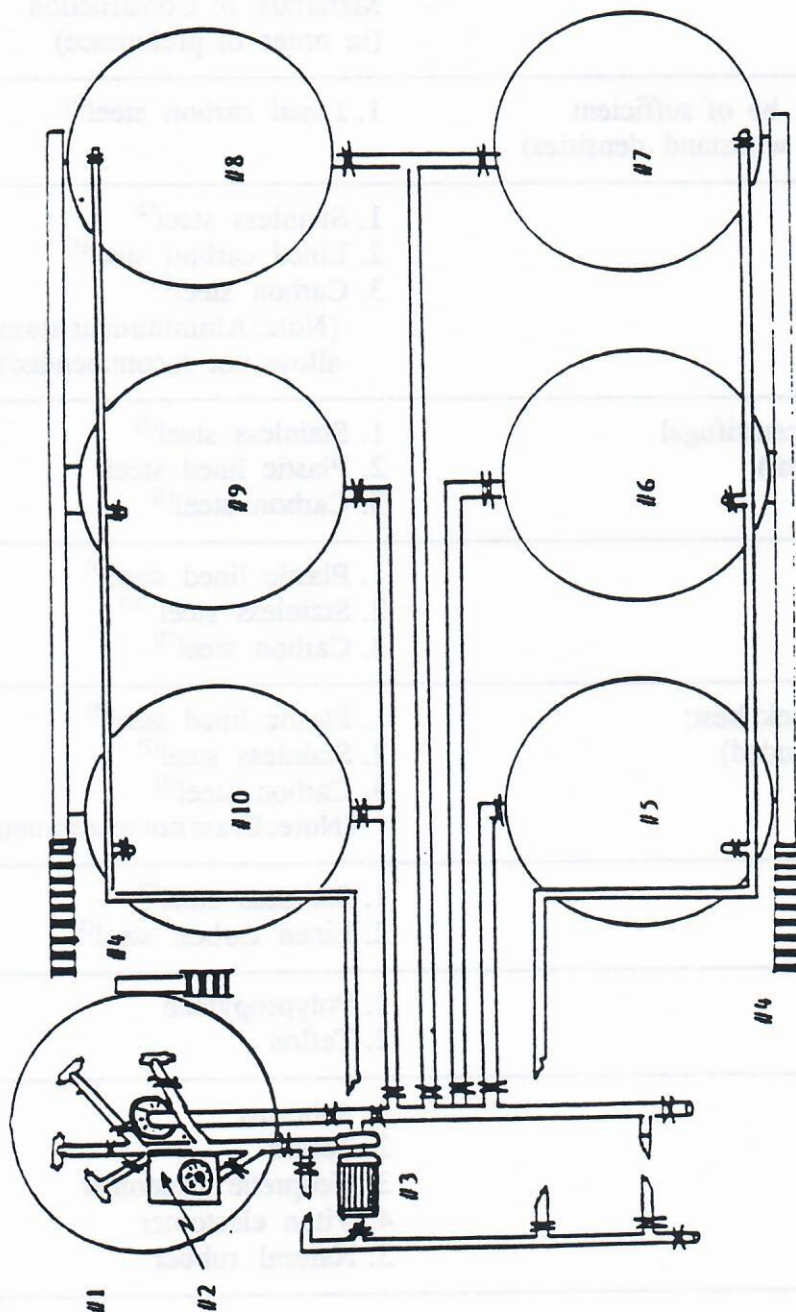
Tank Fillup Line

Area for Additional Tankage

A Barite Bulk Hopper could be added near Mix Tank and Pump

- A single catwalk & stairway should be constructed over suction line and between tanks on Mud Plant.

BRINE MIXING AND STORAGE PLANT *



Discharge Lines and Fillup Lines

Suction Lines

#1 Mix Tank

#2 Hopper

#3 6" Pump with 671 Diesel or 100 HP Electric Motor

#4 Stairs & Walkways

#5 Storage Tank for Zinc Bromide or Formulated Fluid

#6 CaBr₂ Storage

#7 CaBr₂ Storage

#8 CaBr₂

#9 Storage and Tank for Used Fluid

#10 Storage & Tank for Used Fluid

* Tank sizes should be determined by estimated volumes to be used and stored. Either 500 or 1,000 barrel tanks.

**SUGGESTED EQUIPMENT AND MATERIAL OF CONSTRUCTION
FOR POTASSIUM BROMIDE, SODIUM BROMIDE,
CALCIUM CHLORIDE, CALCIUM BROMIDE OR
ZINC BROMIDE/CALCIUM BROMIDE SOLUTION**

Equipment Type	Materials of Construction (in order of preference)
Storage tanks (should be of sufficient structural strength to withstand densities)	1. Lined carbon steel ⁽¹⁾
Tank trucks	1. Stainless steel ⁽²⁾ 2. Lined carbon steel ⁽¹⁾ 3. Carbon steel ⁽²⁾ (Note: Aluminum or aluminum alloys not recommended)
Pumps (direct drive, centrifugal or positive displacement)	1. Stainless steel ⁽³⁾ 2. Plastic lined steel 3. Carbon steel ⁽²⁾
Piping	1. Plastic lined steel ⁽³⁾ 2. Stainless steel ⁽²⁾ 3. Carbon steel ⁽²⁾
Valves (ball or plugcock best; butterfly not recommended)	1. Plastic lined steel ⁽³⁾ 2. Stainless steel ⁽²⁾ 3. Carbon steel ⁽³⁾ (Note: Brass not recommended)
Filter Housings	1. Stainless steel ⁽²⁾ 2. Lined carbon steel ⁽¹⁾
Filter Elements	1. Polypropylene 2. Teflon
Gaskets and Spacers	1. Asbestos 2. Teflon 3. Neoprene elastomer 4. Viton elastomer 5. Natural rubber

Hoses

1. Viton (to 450°F) elastomer
 2. Neoprene (to 250°F) elastomer
 3. Silicone (to 450°F)
 4. Buna N (to 250°F)
 5. Isoprene (to 150°F)
 6. Fluorinated ethylene propylene (to 400°F)
-

(1) Suggested linings for carbon steel tanks:

Epoxy-phenolic (Plasite 7122, Amercoat 75, Phenoline 373 or equivalent)

Phenolic (Plasite 3066 or equivalent)

Epoxy (Chempon 2310R or equivalent)

Coal Tar Epoxy (Tarset Standard or equivalent)

Vinyl Ester (Plasite 4030)

Note: Zinc linings are not suitable. (Dimetcote 4, Carbozinc 11)

- (2) Stainless steel or unlined steel equipment in contact with clear brine fluids should be cleaned thoroughly after each use or kept hydraulically full at all times to minimize corrosion and possible solid contamination.
- (3) Plastic lined piping and valves with either polypropylene, Kynar or Teflon liners are available.

EARLY EXPERIENCE - PROBLEMS

WELL CONTROL

SWABBING

FLUID DENSITY CUT

FLUID LOSSES

TRANSFER

PUMP SUCTIONS

LEAKS

OPERATOR ERRORS

EXCESSIVE CONTAMINATION

LIMITED STORAGE

FLUID LOSSES TO FORMATION

UNRELIABLE GEL PERFORMANCE

WELL CONTROL

FILTERING

POOR DISPLACEMENTS

TRANSPORTATION EQUIPMENT

CYCLONES

SETTLING TIME

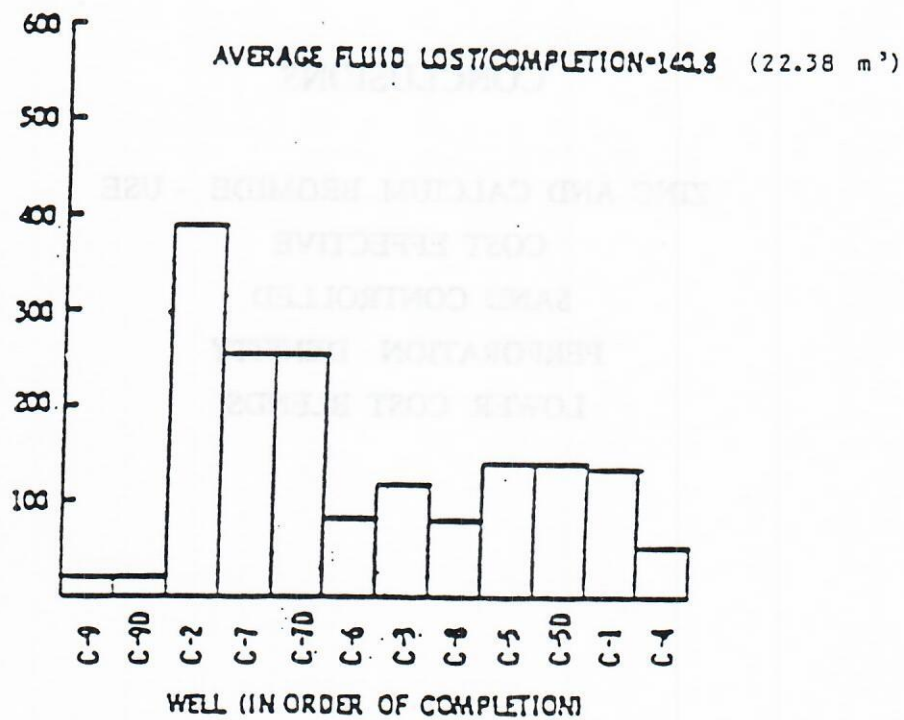
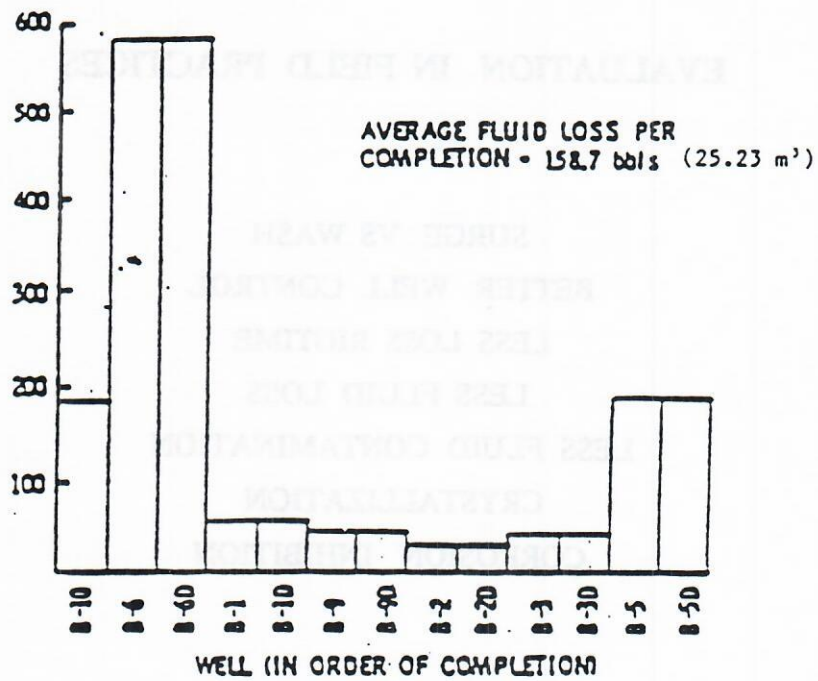
FILTER BYPASSING

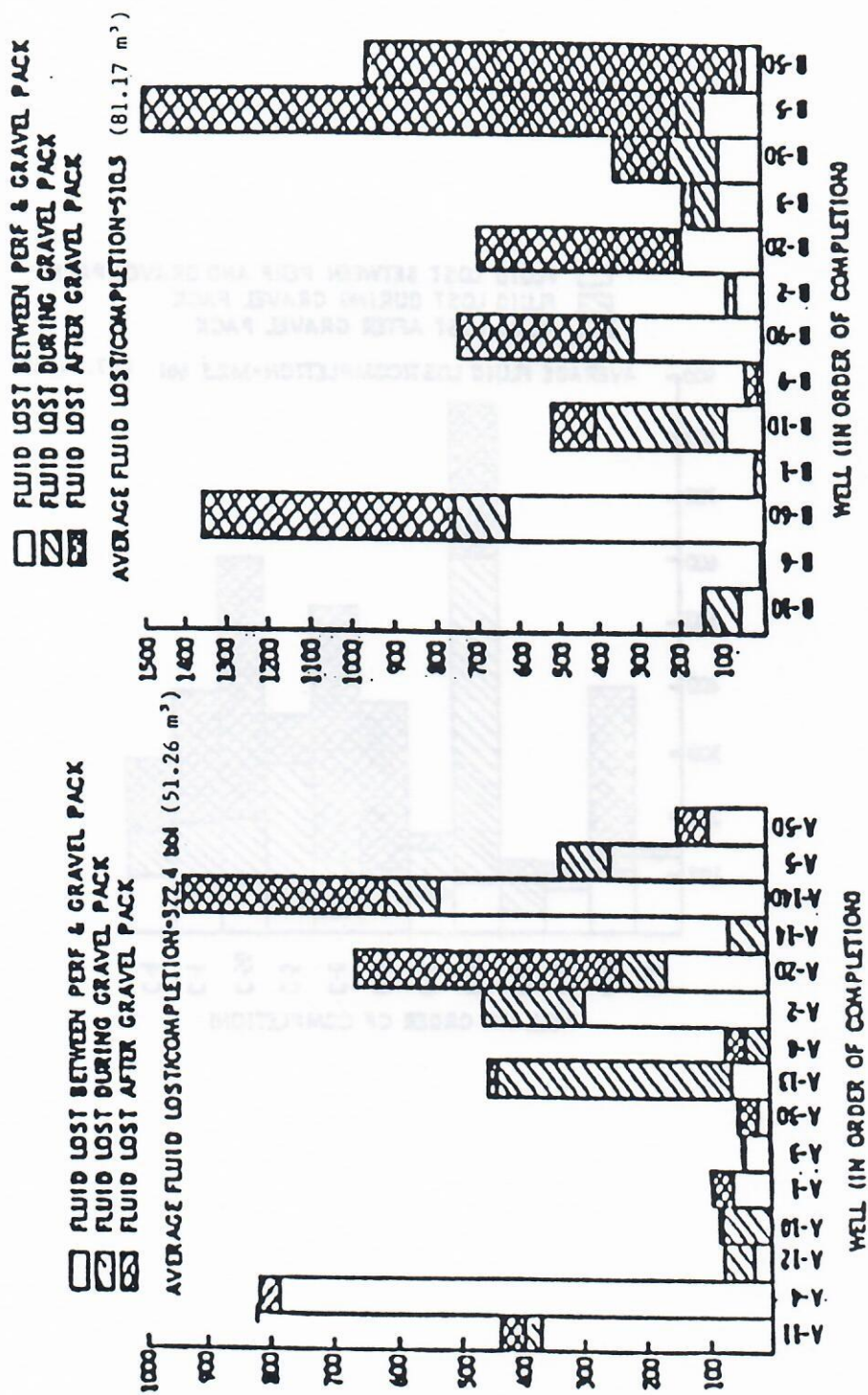
EVALUATION IN FIELD PRACTICES

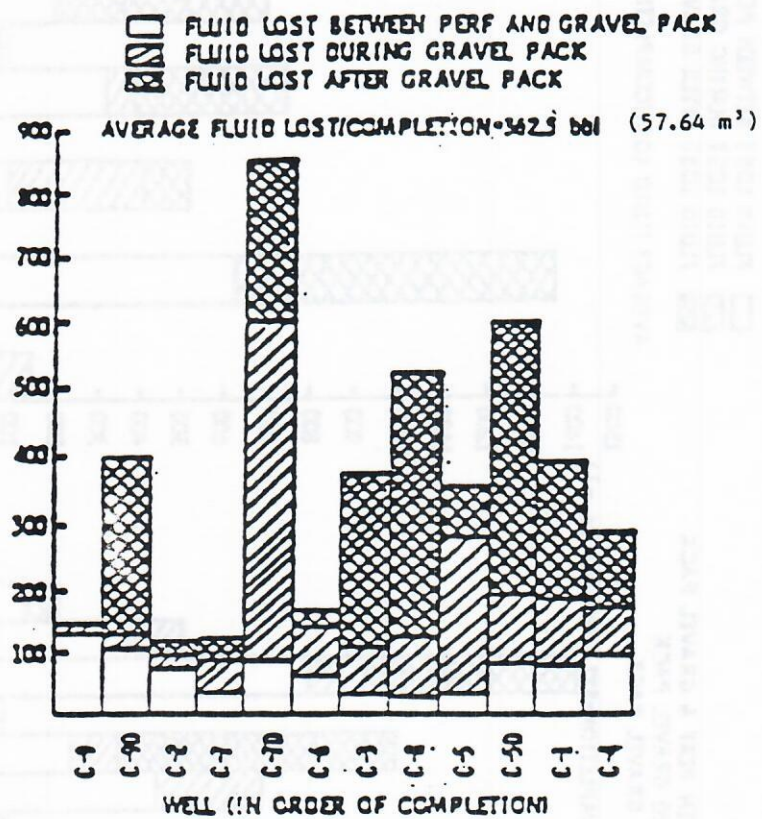
**SURGE VS WASH
BETTER WELL CONTROL
LESS LOSS RIGTIME
LESS FLUID LOSS
LESS FLUID CONTAMINATION
CRYSTALLIZATION
CORROSION INHIBITION**

CONCLUSIONS

**ZINC AND CALCIUM BROMIDE - USE
COST EFFECTIVE
SAND CONTROLLED
PERFORATION DENSITY
LOWER COST BLENDS**







DRILLING ADVANTAGES OF BRINES

INCREASED PENETRATION RATES

FEWER BITS

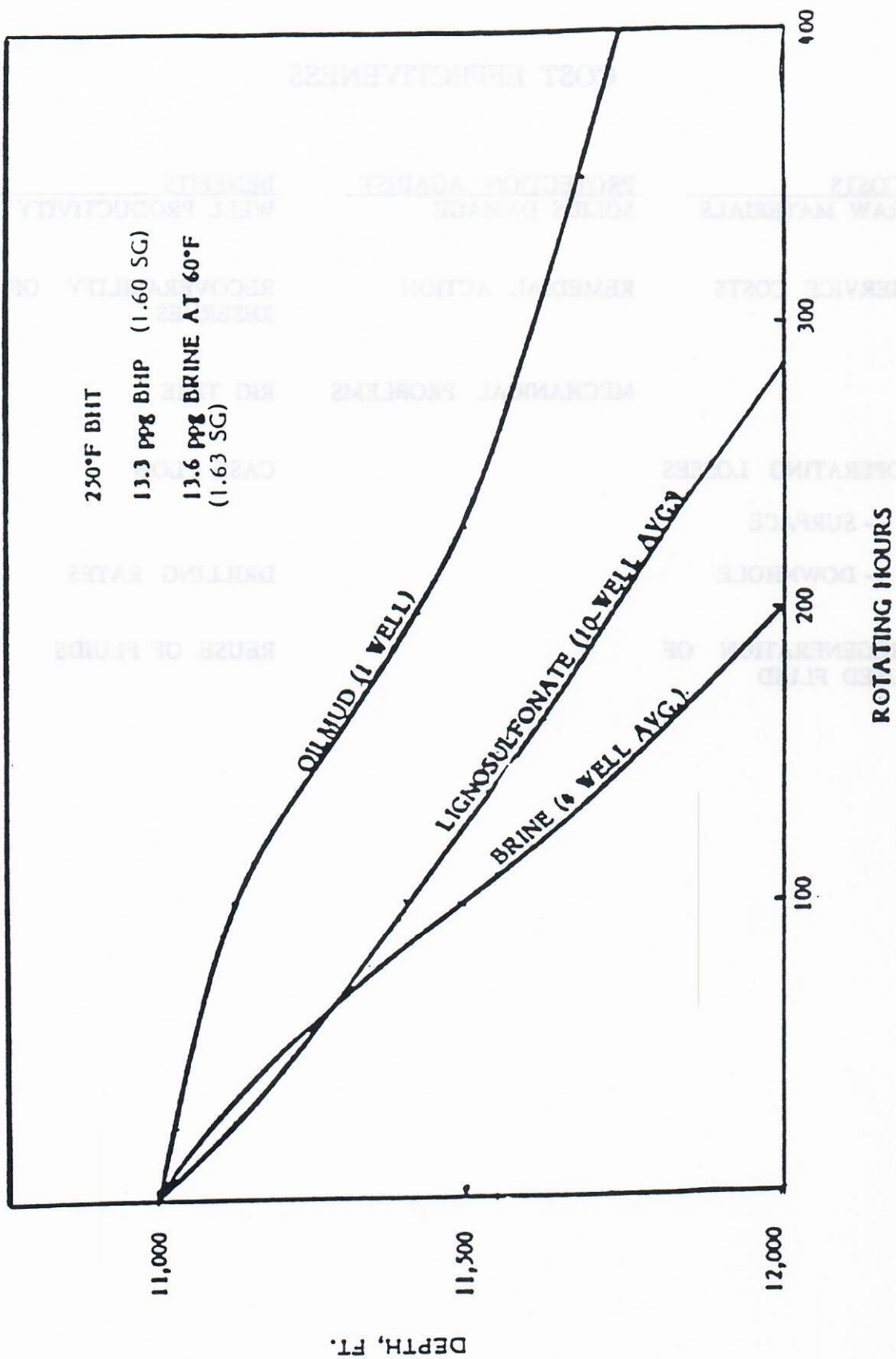
LESS FILL ON BOTTOM

COST SUMMARY

BRINE COST	65,800
FILTERING	10,000
STORAGE	500
SAFETY EQUIPMENT	2,000
DISPLACEMENT	<u>2,000</u>
GROSS COST	80,300

SAVINGS

COST OF LIGNOSULFONATE	39,000
SAVE 2 DAYS RIG TIME	24,000
SAVE 2 BITS	<u>4,000</u>
GROSS SAVINGS	67,000
ADDED COST OF BRINE/WELL	13,300



COST EFFECTIVENESS

<u>COSTS</u>	<u>PROTECTION AGAINST</u>	<u>BENEFITS</u>
RAW MATERIALS	SOLIDS DAMAGE	WELL PRODUCTIVITY
SERVICE COSTS	REMEDIAL ACTION	RECOVERABILITY OF RESERVES
	MECHANICAL PROBLEMS	RIG TIME
OPERATING LOSSES		CASH FLOW
--- SURFACE		DRILLING RATES
--- DOWNHOLE		
REGENERATION OF USED FLUID		REUSE OF FLUIDS

KEY WELL SITE GUIDELINES

COMMUNICATE

QUALIFIED SUPERVISION

COORDINATION (SCHEDULE)

CLEAN

CEMENT (SPACERS)

COVERED TANKS

REMOVE SOLIDS (FILTERING)

CHECK FILTER PERFORMANCE

MIXING - "FISHEYES"

PROPER POLYMERS

CLEAN FIELD WATER (KILL FLUIDS)

UNPAINTED TOOLS

PIPE DOPE

SAFETY

FLUID SYSTEM CHECK LIST

WASH ALL TANKS AND SQUEEGEE TO REMOVE WATER

SEAL DUMP VALVES

ADD WATER TO ONE TANK. WATER IS TO BE USED IN
CLEANING LINES, PUMP, DESILTER, DEGASSER AND IN CHECKING
FOR LEAKS.

FLUSH ALL TANKS, LINES, PUMPS, AND EQUIPMENT. THEN CHECK
ALL EQUIPMENT FOR LEAKS.

INSURE THAT ALL PITS AND LINES ARE CLEANED OF EXCESSIVE WATER
BEFORE PUMPING COMPLETION FLUID INTO THEM.

REPAIR LEAKS BEFORE PUMPING COMPLETION FLUID.

QUICK CHECK LIST

DUMP VALVES

DESILTER LINES

DEGASSER LINES

BUTTERFLY VALVE BETWEEN CENTRIFUGAL PUMPS

CENTRIFUGAL

MUD CLEANER

GATE VALVE BETWEEN SETTLING AND RESERVE PITS

MUD DITCH

SHALE SHAKER

BUTTERFLY VALVE ON FLOWLINE TO DOUBLE DECK SHAKER

PIT INSPECTION PLATES

FLOWLINE, BETWEEN BELL NIPPLE AND SLIP JOINT

WATER LINES LEADING TO PITS

TRANSFER PROCEDURE

1. STOP TRUCKS BEFORE THEY ARRIVE ON LOCATION TO MAKE SURE THAT NO MORE TRUCKS GO ON LOCATION THAN CAN BE HANDLED AT ONE TIME.
2. PUMP FLUID INTO PITS.
3. MONITOR THE PUMPING OPERATION TO DETECT ANY LEAKS IN HOSES OR FITTINGS.
4. DOUBLE CHECK EACH TANK TO MAKE SURE THERE ARE NO LEAKS IN THE VALVES, LINES, OR IN THE TANK ITSELF.
5. AFTER PUMPING, CHECK THE FLUID VOLUME BY EXAMINING THE WEIGHT TICKET AND/OR PIT CALCULATIONS.
6. MAKE SURE THAT THE VACUUM TRUCK IS COMPLETELY EMPTY. VISUALLY CHECK TO INSURE THAT AS MUCH FLUID AS POSSIBLE HAS BEEN PUMPED FROM THE TRUCK.
7. WHEN THE TRANSFER IS COMPLETED, ADVISE THE RIG SUPERVISOR.

PRIOR TO DISPLACEMENT

- A. DETERMINE IF THERE IS TANK SPACE AVAILABLE ON THE RIG TO HOLD ALL MUD BEING DISPLACED.
- B. DETERMINE IF THE FLUID NEEDS TO BE PUMPED INTO BOATS OR TRUCKS DURING DISPLACEMENT.
- C. DETERMINE IF THERE IS TANK SPACE AVAILABLE FOR SPACERS AS THEY RETURN TO THE SURFACE.
- D. DETERMINE IF ALL PERSONNEL ARE COORDINATED AND UNDERSTAND DISPLACEMENT PROCEDURES.

DISPLACEMENT PROCEDURES

DISCUSS DISPLACEMENT PROCEDURES

CONDITION THE MUD IN THE HOLE

PUMP THE APPROPRIATE SPACERS FOLLOWED BY THE BRINE

CHECK THE BRINE DENSITY AND ADJUST IF NECESSARY

FILTER FLUID UNTIL CLEAN

RETURN FILTERED FLUID TO THE CIRCULATION SYSTEM

CONCLUSION

KEY TO SUCCESS - PLANNING

TAKE TIME TO PLAN AND WORK PLAN

LOGISTICS

PROPER FLUIDS - TESTING

RIG PREPARATION

SCHEDULING TRANSPORTATION

SAFE PERFORMANCE

STEPS TO HIGHER PERFORMANCE PRODUCERS

CLEAN FLUIDS

ADEQUATE PERFORATIONS

EFFECTIVE PERFORATION CLEANUP

EFFICIENT GRAVEL PACK

PROPER INITIATION OF PRODUCTION

PRODUCTION INDEX - BEFORE PROGRAM ≤ 2

DURING PROGRAM 2-6

CURRENT TECHNIQUES 6-60

MOST 20 OR GREATER

THE COST OF TIME, EQUIPMENT AND LABOR EXPENDED
PREPARING FOR A PROPER AND CLEAN DISPLACEMENT IS
QUICKLY PAID FOR IN EXTRA RECOVERED PRODUCTION.

CASE STUDY

LOCATION: HIGH ISLAND, OFFSHORE GULF COAST

FORMATION DEPTHS: 8,500'-13,000'(2,591-3962 m)

NO. OF WELLS COMPLETED: 27

COMPLETION METHOD: INSIDE CASING GRAVEL PACK, SOME DUAL COMPLETIONS

BRINE USED: 14.9 (1.79 SG) 15.6 ppg (1.87 SG) CALCIUM CHLORIDE/
CALCIUM BROMIDE/ZINC BROMIDE BLEND

BRINE LEFT AS PACKER FLUID: YES

PRODUCTIVITY: ONE AT 6,700 b/d OIL, ELEVEN AT OVER 1,000 b/d OIL

COMMENTS: "(USER) WAS REWARDED WITH THE HIGHEST RATE OIL WELL EVER TO PRODUCE IN THE GULF OF MEXICO. THIS WELL TESTED AT JUST OVER 6,700b/d OF OIL IN EARLY 1981. IN ADDITION, ELEVEN OTHER WELLS TESTED AT RATES IN EXCESS OF 1,000 b/d." (SOURCE: PETROLEUM ENGINEERING INTERNATIONAL, NOVEMBER 15, 1981).

THE PURPOSE OF A FLUID IS -

TO CONTROL THE WELL.

PROTECT THE FORMATION FROM DAMAGE DURING THE
WORKOVER.

THE MAIN GOAL OF THE WORKOVER -

TO RESTORE OR TO INCREASE PRODUCTION.

NOT TO CAUSE THE WELL TO BE ABANDONED.

SYNERGY FLUIDS

FUNCTION:

Completion, Workover, Drill-In Fluid

GENERAL DESCRIPTION:

Clear Liquid

PRODUCT: CALCIUM BROMIDE, 52%

PRODUCT BENEFITS:

- * Pure solution, nondamaging to the formation
- * Chemically and thermally stable in the hole
- * Can be modified by a range of additives to respond to downhole condition
- * Can be blended with other solutions of bromides and chlorides to provide a range of densities up to 19.2 lbs/gal

RECOMMENDED USES:

Calcium bromide brine can be used with calcium chloride solid to formulate nondamaging fluids of densities from 11.7 lbs/gal to 15.1 lbs/gal.

When used with calcium/zinc bromide 19.2 lbs/gal, can formulate nondamaging fluids up to 19.2 lbs/gal density.

These fluids are the basis for nondamaging completion, workover and drill-in fluids. For use when the best possible productivity is required from your well.

PRODUCT DESCRIPTION:

Color:	Clear, water-white
Density:	14.2 lbs/gal
pH (1:10 dilution):	7
Crystallization Point °F:	20
Storage:	Epoxy-lined tanks
Packaging:	Bulk truck or flexibags
Spills:	See MSDS, check on local codes for disposal

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheet, MSDS
- * Additional information on formulation with calcium bromide brines
- * Additional information on additives and modifiers for use with calcium bromide brine

CALCIUM BROMIDE BRINE

Material Safety Data Sheet

CaBr₂, 52%

USE: Clear, 52% Calcium Bromide Brine, alone (at 14.2 lbs/US gallon) or combined with calcium chloride will give oil - and gas-well completion, workover and packer brines with bulk densities of up to 15.1 lbs/US gallon. Brines with crystallization points of as low as -30°C are supplied for use in cold climates.

DESCRIPTION: Water-clear, nonvolatile, odorless liquid.

SPECIFICATION:

Assay, minimum %	52
Density 25°C/4°C, minimum	1.70
bulk, lb/gallon (US) minimum	14.2
Boiling point, °C	130
Crystallization point, °C	<-7
pH (1:10 dilution), minimum	7
Calcium bromate, maximum ppm	20
Ammonia (ion), maximum ppm	10

FLAMMABILITY & EXPLOSIVITY: Calcium Bromide brine is stable, nonflammable and nonexplosive. In case of intense fires, irritant hydrogen bromide or bromine fumes may be released.

TOXICITY: Calcium Bromide brine may irritate the eyes and slightly irritate the skin. There is no danger from inhalation, unless aerosol misting occurs.

ACUTE TOXICITY: Oral: LD₅₀ rat 4000 mg/kg.
A TLV (Threshold Limit Value) has not been established.

STORAGE & HANDLING: Protect containers from damage. Store in a cool, well ventilated, dry area. Mild steel or stainless steel containers may be used for limited periods only. Prevent contact with the eyes and skin. Wear cup-type chemical safety goggles or face shield. Respiratory protection is not required. In case of fires or aerosol misting conditions, use self-contained breathing apparatus. Wash thoroughly with soap and water after handling. Do not wear leather boots or gloves, they will dehydrate an crack.

CLEAN-UP:

Spills and/or Disposal: Contain spills. Cover spills with sawdust or other inert absorbant; shovel into suitable containers and remove to an approved disposal site.

FIRST AID:

Skin and eye contact: Wash with water, immediately, for 15 minutes.

Ingestion: Induce vomiting only if conscious, call for medical assistance. Remove contaminated clothing; launder before reuse.

TRANSPORT:

Calcium Bromide Brine is mildly corrosive. DOT has no labeling requirement, the material is not hazardous. Calcium bromide brine has not been classified by IMCO.

SYNERGY FLUIDS

FUNCTION:

Completion, Workover, Drill-In
Applications -- Alternative to liquid CaBr_2

GENERAL DESCRIPTION:

White Free-Flowing Powder

PRODUCT: CALCIUM BROMIDE, 95%

PRODUCT BENEFITS:

- * Powder from calcium bromide allows for economical transportation compared with liquid product.
- * Ease of handling and inventory control when handling solids vs liquid.

RECOMMENDED USES:

- * As primary source of calcium bromide when cost of transportation is major portion of product cost.
- * Primary source of calcium bromide when tank availability or transportation not readily available for liquid product.
- * For 14.2 lbs/gal calcium bromide, and rapid weight up of brines at rig site.
- * For remedial work on brines -- to build weight without large increases in volume.

PRODUCT DESCRIPTION:

Color:	White Powder
Assay, minimum %	95
Solubility (g/100g in water)	60
Storage:	Protect containers from damage. Store in cool, well-ventilated dry area. Product is hygroscopic.
Packaging:	55# polyethylene bags. Packaged 34 or 40 sx/triwall. Triwall is a heavy duty cardboard container.
Handling:	Consult MSDS

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheet, MSDS
- * Mixing information and charts
- * Additional information on other bromide brines, solid and liquid
- * Information on additives and modifiers for brines

CALCIUM BROMIDE POWDER

Material Safety Data Sheet

USES:	Calcium Bromide powder can be dissolved in water to yield clear brine solutions weighing up to 14.2 ppg. It can be used where the economies of shipping a powdered product outweigh the convenience of using liquid CaBr_2 . It is used for raising brine densities of bromide brines without large increase in volume.
DESCRIPTION:	A white, free-flowing powder - hygroscopic and odorless.
SPECIFICATION:	Assay, minimum % 95 Solubility, g/100g in water 60
FLAMMABILITY & EXPLOSIVITY:	Calcium bromide is stable, nonflammable and nonexplosive. In intense fires, hydrogen bromide or bromine fumes may be released.
TOXICITY:	Calcium bromide powder may irritate the eyes and skin.
ACUTE TOXICITY:	Oral: LD_{50} rat 2500 mg/kg. A TLV (Threshold Limit Value) has not been established.
STORAGE & HANDLING:	Protect containers from damage. Store in a cool, well-ventilated, dry area. Prevent contact with eyes and skin by body-covering clothes, rubber boots, nonpermeable gloves, cup-type safety goggles and dust mask. In case of fire, use self-contained breathing apparatus. Wash thoroughly with soap and water after handling.
CLEAN-UP:	Spills and/or Disposal: Cover spills with sawdust or other inert absorbant; shovel into suitable containers and remove to approved disposal site.
FIRST AID:	Skin and eye contact: Wash with water, immediately, for 15 minutes. Ingestion: Induce vomiting only if conscious; call for medical assistance. Remove contaminated clothing; launder before reuse.
PACKAGING:	Calcium bromide powder is available in moisture proof plastic bags in heavy wall cardboard containers.
TRANSPORTATION:	Calcium bromide powder is not hazardous. No labelling requirements (DOT). Not classified (IMCO).

SYNERGY FLUIDS

FUNCTION:

Completion, Workover, Drill-In Fluid

GENERAL DESCRIPTION:

Transparent Liquid, high
solution density

PRODUCT: CALCIUM/ZINC BROMIDE, 71-77%

PRODUCT BENEFITS:

- * Pure solution, contains no solids, nondamaging to the formation
- * Chemically and thermally stable in the hole
- * Can be modified by a range of additives to respond to downhole conditions
- * Can be blended with other bromides and chlorides to form a range of solution densities up to 19.2 lbs/gal
- * Extremely high weight as a pure solution allows calcium/zinc bromide to be used on location for rapid weight of other completion fluids, without introducing solids and the consequent possible formation damage.

RECOMMENDED USES:

- * To prepare nondamaging, solids free, fluids in the range 15.1 lbs/gal to 19.2 lbs/gal.
- * Nondamaging kill fluid, or high density rapid weight-up fluid for nondamaging completions.
- * These fluids are an integral part of the nondamaging, completion, workover and drill-in fluids from 15.1 to 19.2 lbs/gal.

PRODUCT DESCRIPTION:

Color:	Honey to clear, transparent liquid
Assay, % Zinc bromide	52-55
Calcium bromide	19-22
Density (lbs/gal)	19.2
pH (1:10 dilution)	5-7
Crystallization Point °F	20
Storage:	Use epoxy-lined tanks, use stainless steel only for limited periods. Keep tank as full as possible.
Packaging:	Calcium/Zinc bromide is available in 340 kg plastic drums (0.93) or polyethylene lined steel drums containing one bbl or from bulk.
Spills:	Observe local codes, consult MSDS sheet.

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheet, MSDS
- * Additional information on other bromide brines compatible with this product.
- * Information on a range of additives, modifiers, corrosion inhibitors suitable for calcium/zinc bromide brines.

ZINC BROMIDE/CALCIUM BROMIDE BRINE **Material Safety Data Sheet**
ZnBr₂/CaBr₂ 71-77%

USE: Zinc Bromide/Calcium Bromide Brine is used in oil and gas well workover, completion, and packer fluids, when prevailing pressures require densities of up to 2.3 (19.2 lbs/US gallon).

DESCRIPTION: A honey-colored or clear, transparent, nonvolatile liquid.

SPECIFICATION: Assay, range %: zinc bromide 52-55
 calcium bromide 19-22
 inhibitor 0.5
Density 25°C/4°C, minimum 2.3
 bulk, lb/gal (US) 19.2
Boiling point, °C 136
Crystallization point, °C <-7
pH (1-10 aqueous dilution) 5-7

FLAMMABILITY & EXPLOSIVITY: Zinc bromide/calcium bromide solutions are stable, non-flammable and nonexplosive. In intense fires, hydrogen bromide or bromine fumes may be released.

TOPXICITY: This blend brine is more corrosive than calcium bromide brine on its own, so that some extra care is needed in handling. Zinc bromide/calcium bromide solutions may strongly irritate the eyes and slightly irritate the skin.

ACUTE TOXICITY: LD₅₀ 1300 mg/kg - moderate hazard.

STORAGE & HANDLING: Protect containers from damage. Store in epoxy-resin lined tanks, in a cool, well-ventilated, dry area. Mild steel or stainless steel containers may be used for limited periods only. Prevent contact with the eyes and skin. Wear body-covering clothes, rubber boots and nonpermeable gloves. Wear cup-type chemical safety goggles or face shield. Respiratory protection is not required. In case of fires or aerosol misting conditions, use self-contained breathing apparatus. Wash thoroughly with soap and water after handling. Do not wear leather shoes or gloves; they will harden and dehydrate on exposure to the brine.

CLEAN-UP: Spills and/or Disposal: Contain spill. Recover spill material with sawdust or other absorbent; shovel into suitable containers and remove to an approved disposal site. Avoid flushing into streams, lakes, or ponds.

FIRST AID: Skin and eye contact: Flush with water for 15 minutes; call for medical assistance if irritation persists.
Ingestion: Do not induce vomiting; call for medical assistance. Remove contaminated clothing; launder before reuse.

PACKAGING: Zinc Bromide/Calcium Bromide brine is supplied in polyethylene or lined steel drums. Packaging specifications are available on request.

TRANSPORT:

Shipping name:	Zinc Bromide
Hazard Class:	ORM-E
Hazardous Substance:	Zinc Bromide
Label:	None required
RQ: (for EPA)	5,000 lbs/2,270 Kgs.
(for DOT)	10,000 lbs/4,540 Kgs.
ID Number:	NA9156

SYNERGY FLUIDS

FUNCTION:

Completion, Workover, Drill-In Fluid

GENERAL DESCRIPTION:

Sodium Bromide, 98.5%

PRODUCT: SODIUM BROMIDE NaBr

PRODUCT BENEFITS:

- * High purity from NaBr, ideal for use where calcium carbonate precipitation is a concern.
- * Rapidly dissolves in water, can be made up to 12.7 lbs/gal.
- * When in solution will not damage the formation or precipitate carbonates.
- * NaBr is produced by a crystallization process, contains fewer impurities than spray dried product or 12.7 lbs/gal solution.

RECOMMENDED USES:

- * Economical form of NaBr.
- * Recommended for areas where transportation costs (of liquid) are prohibitive.
- * Where high purity NaBr is a requirement.
- * Can be mixed in a sodium chloride brine without fear of precipitation. No need to displace to a calcium chloride system.

PRODUCT DESCRIPTION:

Color:

White crystalline, free-flowing powder

<u>Properties</u>	<u>Limits</u>	<u>Typical</u>
NaBr%	97.5 min.	98.5
Loss on Drying %	2 max.	1
Chloride as CL - %	0.5 max.	0.2
Calcium ppm	5 ppm	
Magnesium ppm	1 ppm	
Heavy metals (as Pb) ppm	5 max.	
Arsenic ppm	2 max.	
Iron ppm	10 max.	
Acidity as HCL %	0.02 max.	
Alkalinity as NaOH %	0.02 max.	
Storage and Handling:	Store in cool dry well-ventilated area.	
Package:	55# polyethylene bags, heavy duty cardboard triwall box. 46 bags to the triwall	

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheet. MSDS
- * Additional information on other bromide brines and salts
- * Information on additives and modifiers used in these brines

SODIUM BROMIDE
NaBr

Material Safety Data Sheet

USE: Sodium Bromide, NaBr, can be used to prepare pure solutions up to 12.7 lbs/US gallon for use in completion, workover and packer fluids.

DESCRIPTION: White, free flowing, crystalline solid.

SPECIFICATIONS:

Assay (NaBr), minimum %	98.5
Loss on drying, maximum %	0.5
Density 25°C/25°C	3.203
Melting Point, °C	755
Solubility 25°C, g/100g: in water	48
pH of solution, 5% w/v	5.5-8.5

FLAMMABILITY & EXPLOSIVITY: Sodium Bromide is nonflammable and nonexplosive. When strongly heated, or in an intense fire, may emit bromide fumes.

TOXICITY: Oral: LD₅₀ rat 3.5 g/kg. Slightly toxic.

STORAGE & HANDLING: Store in a dry, cool, well-ventilated area. Protect containers from damage. Avoid inhalation, ingestion and contact with eyes and skin.

FIRST AID:

Inhalation: In case of dizziness or nausea, remove to fresh air and call for medical attention immediately.

Ingestion: Induce vomiting only if conscious. Call for medical attention immediately.

Eye Contact: Flush with plenty of fresh water for at least 20 minutes. Call for medical attention immediately.

Skin Contact: Wash and rinse copiously with water. remove contaminated shoes and clothing. Launder before reuse.

PACKAGING: Sodium bromide is packaged in 55# polyethylene bags. the bags are packed in heavy wall cardboard containers.

REDUCE COMPLETION FLUID COSTS WITH ON-SITE BRINE TESTS

David C. Thomas, staff research scientist, Amoco Production Co., Tulsa, Okla., William R. Kinney, retired vice president, LaMotte Chemical Products Co., Chestertown, Maryland, R. Keith Darlington, manager of Product Development, and Jack L. Lowell, scientist, both with NL Baroid/NL Industries, Inc., Houston.

10-second summary

A newly developed field kit makes on-site brine completion fluid testing practical. Simple titration procedures are used to analyze brine for calcium, zinc, chloride and bromide with accuracy and repeatability that compares favorably with expensive laboratory techniques. This article describes the field testing theory and details analytical procedures used.

THE USE OF EXPENSIVE completion brines and the need for cost control of these fluids led to development of a field-usable brine analysis kit. Lab methods, such as specific ion electrode methods, are suitable for field use because of the delicacy and cost of equipment involved. The criteria set for a field kit were:

- Reasonable accuracy,
- Ruggedness,
- Simplicity both in methods and equipment,
- Speed of analysis and
- Field portability

This article describes development of the kit, methods used and results that can be expected from its proper use. The kit allows the user to analyze a brine for its major components of calcium, zinc, chloride and bromide using simple titration procedures similar to those used in drilling fluid analysis. Calcium and zinc are determined by titration with EDTA (versenate or ethylenediamine tetraacetate) while chloride and bromide are measured by titration with silver nitrate solution.

TABLE 1 - Ammonium persulfate needed to remove bromide

Brine density, <1.514	Brine density, <12.61	(NH ₄) ₂ S ₂ O ₈ gm
1.516-1.658	12.63-13.79	0.10
1.660-1.946	13.83-16.21	0.20
1.948-2.306	16.23-19.21	0.30
		0.40

BRINE ANALYSIS CHEMISTRY

Analysis of heavy completion brines is complicated by use of chloride and bromide and by use of zinc and calcium in the same solution. The main problem confronting the kit developers was not analytical procedures, but separation of interfering ions.

Brine dilution. The simple process of diluting a sample of heavy brine for analysis has a complicating feature when zinc is present on the brine. Zinc forms complexes with chloride, bromide, water and hydroxide in solution. When a very concentrated solution containing these complexes is diluted, an equilibrium may occur that produces a gelatinous precipitate of zinc hydroxide. This gel can interfere with, or spoil, an analysis. Care must be taken to keep this complex from forming during the dilution step by acidification with nitric acid.

Zinc-calcium separation and analysis. Separation of zinc and calcium for quantitative analysis of both ions is somewhat difficult. During kit development, three methods were tested. The first was complexation of zinc with cyanide to produce a soluble, but noninterfering complex.



This complex effectively masked the zinc but, because of large amounts of sodium cyanide needed, was rejected as too dangerous for field use.

The second separation technique tried was precipitation of calcium with fluoride ion to yield insoluble calcium fluoride.



This method was effective, but showed a precipitate in every brine completion fluid. Additionally, calcium fluoride is slightly soluble so analysis must be completed quickly to avoid some error in results.

TABLE 2 - Brine fluid composition in error sensitivity analysis

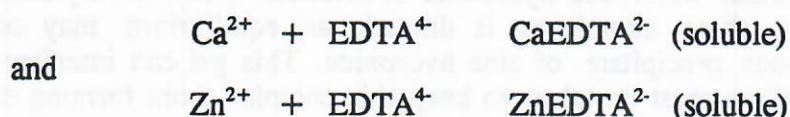
Density:		Ion analysis:	
	16.0 ppg, 1.921 gm/cm ³		
CaCl ₂ :	11.53 wt%	Ca:	10.39 wt%
CaBr ₂ :	31.10 wt%	Zn:	5.83 wt%
ZnBr ₂ :	20.07 wt%	Cl:	7.37 wt%
Water:	37.30 wt%	Br:	39.10 wt%

The separation technique finally chosen was precipitation of zinc with sulfide.



This compound is sufficiently insoluble as to produce no interference in the analysis for calcium. It has the added advantage of allowing the analyst to make qualitative analysis for zinc, thus saving time and chemicals during field work.

Zinc and calcium are determined by titration with EDTA in a similar manner to total hardness or calcium analyses performed on drilling fluids.¹ The solution of EDTA is provided as disodium salt ($\text{Na}_2\text{H}_2\text{EDTA}$) at 0.100 M concentration. The active chelating agent is the EDTA anion (normally written, EDTA^{4-}), that complexes strongly with most divalent ions such as zinc or calcium. The EDTA^{4-} ion exists in the fully ionized form at the analysis pH of 10. Pertinent chemical reactions are:



Calmagite is used as indicator for these titrations to avoid the color change problem frequently encountered with Eriochrome Black T. Analysis proceeds in two separate titrations. The first titration determines total amount of calcium and zinc. The second titration, after precipitation of zinc sulfide, determines amount of calcium present. Zinc concentration is determined by difference.

Chloride-bromide separation and analysis. Chloride and bromide are both analyzed by titration with silver nitrate solution in a similar manner to chloride analysis performed in drilling fluid analysis.² They interfere with one another in the analytical procedure; therefore, separation is required. The only convenient field method of achieving separation is oxidation of bromide to bromine while boiling to remove the evolved bromine. This procedure can be somewhat uncomfortable for the analyst in the field as bromine gas can burn eyes and sting nasal passages. It is strongly recommended that this procedure be done in a very well ventilated area or in a fume hood.

Ammonium persulfate is added to an acidified brine solution to oxidize bromide by the following reaction:



The solution is acidified with nitric acid. The amount of excess persulfate is kept low by incremental additions to minimize an interference of sulfate in titration with silver nitrate to follow. Table 1 shows amounts of ammonium persulfate to add for different brine concentrations.

This first analysis determines the amount of chloride present. After bromine evaluation, pH is adjusted to between 6 and 7 with 15% sodium hydroxide. Use either indicator strips or a pH meter to establish the correct value. This pH adjustment is important because the solubility of silver chromate formed by indicator reaction becomes excessive below pH 6 and gives poor end points.³ Silver sulfate (sulfate coming from the persulfate reaction) can interfere if pH is too high.⁴ Keeping pH below 7 minimizes this problem. Total bromide and chloride is

determined in a second titration and bromide concentration is obtained by difference.

The logical sequence of analysis for an unknown brine is shown in Fig. 2. One must assume initially that all ions are present. If separate knowledge indicates that no zinc or bromide are present, procedures can be simplified considerably. If no zinc is present, a simple calcium titration will suffice for the cations. If either chloride or bromide are absent, the halide analysis is correspondingly simplified. The analyst must use separate knowledge available to him to avoid unnecessary work.

CALCULATIONS

Data from analytical procedures must be converted from milliliters of titrant to weight percent salts so that meaningful use of results can be made. The original brine density is required to convert from volume units to mass units. The original brine solution is diluted to one-fifth its original concentration to reduce sampling errors and to keep titrant volumes reasonable.

TABLE 3 - Density measurement error contribution to analysis error

Density, ppg gm/cm ³	Low	Correct	High
	15.9	16.0	16.1
	1.909	1.921	1.933
Analysis			
Ca, wt%	10.45	10.39	10.32
Zn, wt%	5.85	5.82	5.79
Cl, wt%	7.41	7.37	7.32
Br, wt%	39.34	39.10	38.82

Factors required are determined as follows:

$$\begin{aligned}
 \text{wt\% Ca}^{2+} &= V_c/D_B \times \\
 &\quad (0.1 \text{ m EDTA}/1,000 \text{ ml Soln.}) \times \\
 &\quad (5) (40.08\text{g/mCa})(100) \\
 &= V_c/D_B(2.004) \\
 &= 2.00(V_c/D_B)
 \end{aligned}$$

$$\begin{aligned}
 \text{wt\% Zn}^{2+} &= [(V_{\text{cz}} - V_{\text{c}})/D_{\text{B}}] \times \\
 &\quad (0.1 \text{ m EDTA}/1,000 \text{ ml})(5.0) \times \\
 &\quad (65.38 \text{ g/m Zn})(100) \\
 &= (3.269) (V_{\text{a}} - V_{\text{c}})/D_{\text{B}} \\
 &= (3.27) (V_{\text{a}} - V_{\text{c}})/D_{\text{B}}
 \end{aligned}$$

$$\begin{aligned}
 \text{wt\% Cl}^- &= (V_{\text{Cl}}/D_{\text{B}}) \times \\
 &\quad (0.141 \text{ m Ag}/1,000 \text{ ml}) \times \\
 &\quad (5.0)(35.45 \text{ g/m Cl})(100) \\
 &= (2.4992) V_{\text{Cl}}/D_{\text{B}} \\
 &= 2.50(V_{\text{Cl}}/D_{\text{B}})
 \end{aligned}$$

$$\begin{aligned}
 \text{wt\% Br}^- &= [(V_{\text{ClBr}} - V_{\text{Cl}})/D_{\text{B}}] \times \\
 &\quad (0.141 \text{ m Ag}/1,000 \text{ ml}) \times \\
 &\quad (5.0)(79.90 \text{ g/m Br})(100) \\
 &= [(V_{\text{ClBr}} - V_{\text{Cl}})/D_{\text{B}}] (5.633) \\
 &= 5.63(V_{\text{ClBr}} - V_{\text{Cl}})/D_{\text{B}}
 \end{aligned}$$

Symbols used have the following meanings:

- D_{B} = brine density in gm/cc,
 V_{c} = volume of 0.100M EDTA required to titrate Ca^{2+} after Zn^{2+} precipitated in ml,
 V_{a} = volume of 0.100M EDTA required to titrate both Ca^{2+} and Zn^{2+} in ml,
 V_{Cl} = volume of 0.141M AgNO_3 solution required to titrate Cl^- after Br_2 evolution in ml,
 V_{ClBr} = volume of 0.141M AgNO_3 solution required to titrate both Cl^- and Br^- in ml.

Computed concentrations can be checked to test accuracy of results by an anion-cation charge balance because electroneutrality must be maintained. The number of moles of calcium plus zinc is determined and compared to the number of moles of chloride plus bromide. Since calcium and zinc are divalent, there must be two chloride or bromide ions for each calcium or zinc ion. In a correct analysis, the ratio of anions to cations must be approximately 2.0:

$$\begin{aligned}
 &[(\text{wt\% Cl}/35.45) + (\text{wt\% Br}/79.90)] / \\
 &[(\text{wt\% Ca}^{2+}/40.08) + (\text{wt\% Zn}^{2+}/65.38)] \\
 &= 2.0.
 \end{aligned}$$

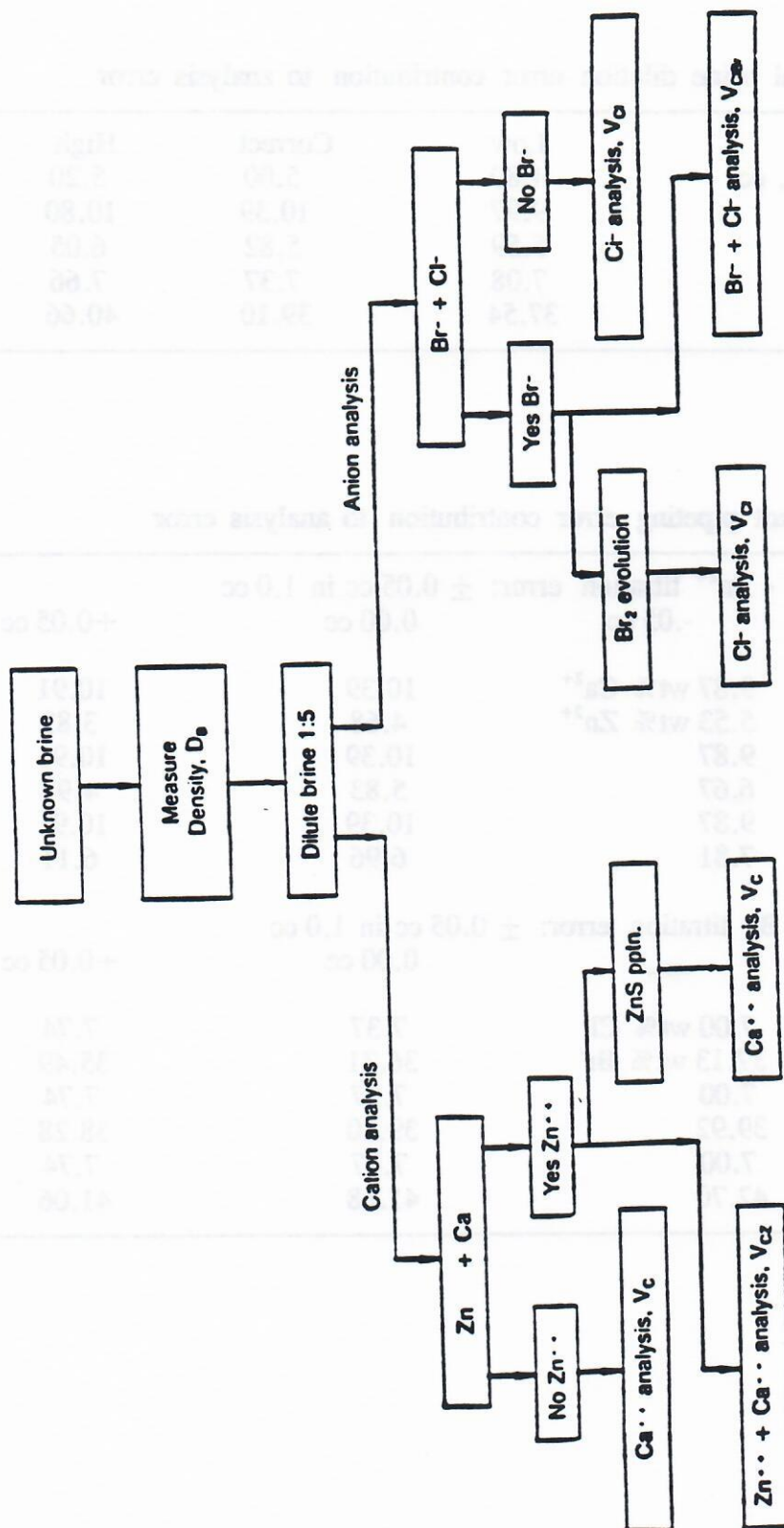


Fig. 2—Prior knowledge of fluid composition can simplify analysis. For example, if no zinc is present, calcium titration will suffice for cations. And if either chloride or bromide are absent, halide analysis is correspondingly simplified.

TABLE 4 - Initial brine dilution error contribution to analysis error

	Low	Correct	High
Assumed volume, cc	4.80	5.00	5.20
Ca, wt%	9.97	10.39	10.80
Zn, wt%	5.59	5.82	6.05
Cl, wt%	7.08	7.37	7.66
Br, wt%	37.54	39.10	40.66

TABLE 5 - Aliquot pipeting error contribution to analysis error

Ca ²⁺ - Zn ²⁺ titration error: ± 0.05 cc in 1.0 cc			
V _c	-0.05 cc	0.00 cc	+0.05 cc
V _{cz}			
	9.87 wt% Ca ²⁺	10.39	10.91
-0.05 cc	5.53 wt% Zn ²⁺	4.68	3.83
0.00 cc	9.87	10.39	10.91
	6.67	5.83	4.97
+0.05 cc	9.87	10.39	10.91
	7.81	6.96	6.11
Cl ⁻ - Br ⁻ titration error: ± 0.05 cc in 1.0 cc			
V _{cl}	-0.05 cc	0.00 cc	+0.05 cc
C _{clBr}			
	7.00 wt% Cl ⁻	7.37	7.74
-0.05 cc	37.13 wt% Br ⁻	36.31	35.49
0.00 cc	7.00	7.37	7.74
	39.92	39.10	38.28
+0.05 cc	7.00	7.37	7.74
	42.70	41.88	41.06

TABLE 6 - Endpoint detection and buret reading error contribution to analysis error

Ca ²⁺ - Zn ²⁺ titration error: ± 0.2 cc			
V _c	-.2	0.00	+0.2
V _{cz}	10.18 wt% Ca ²⁺	10.39	10.60
	5.83 wt% Ca ²⁺	5.48	5.14
-0.2			
0.0	10.18	10.39	10.60
	6.16	5.83	5.48
+0.2	10.18	10.39	10.60
	6.50	6.16	5.82
Cl ⁻ - Br ⁻ titration error: ± 0.2 cc			
V _{Cl}	-.2	0.00	+0.2
V _{ClBr}	7.10 wt% Cl ⁻	7.37	7.63
-0.2	39.10 wt% Br ⁻	38.53	37.92
0.0	7.10	7.37	7.63
	39.68	39.10	38.51
+0.2	7.10	7.37	7.63
	40.26	39.70	39.10

If the ratio is not close to two, then analysis is incorrect or computations are in error. A contaminated sample will also produce an error. The analyst should first check calculations and, if necessary, repeat the entire analysis. It must be noted here that most field brines contain a small amount of NaCl or KCl as a contaminant. The ratio may be slightly greater than two for that reason (2.004 instead of 2.000). Acceptable ranges of this ratio is 2.00 ± 0.07 for field analyses.

Individual ion analyses can be converted to appropriate salts by using the following equations that assume that three salts could be present: CaCl₂, CaBr₂ and ZnBr₂. The only source of chloride is CaCl₂ and the only source of zinc is ZnBr₂. These equations can be used for any currently used brine completion fluid from simple CaCl₂ to the most complicated three-salt system. If zinc or chloride are not present, simply set the appropriate value to zero. The equations are:

$$\begin{aligned}
 \text{wt\% CaCl}_2 &= 1.565 \times \text{wt\% Cl} \\
 \text{wt\% ZnBr}_2 &= 3.444 \times \text{wt\% Zn}^{2+} \\
 \text{wt\% CaBr}_2 &= 4.987 (\text{wt\% Ca}^{2+} - 0.565 \times \text{wt\% Cl})
 \end{aligned}$$

ERROR SENSITIVITY ANALYSIS

An error sensitivity analysis was performed on methods used with the kit to determine where major sources of error might be. It is assumed in this analysis that all glassware pipets and brushes are properly calibrated and used. In addition, it is assumed that titrating solutions have been properly standardized, stored and kept free from contamination.

Major potential sources of error are:

- Inaccurate density measurement of original brine
- Improper dilution of concentrated brine during pipetting
- Improper transfer pipetting of diluted brine to titration flasks
- Improper choice of end point during titration or incorrect reading of burets.

These sources of error have been analyzed for a test brine that includes all four ions of interest. Its composition is shown in Table 2. The composition was chosen to match a summer blend, 16.0 ppg brine with about a 40° F crystallization temperature.

Small errors in density measurement (± 0.1 ppg, ± 0.012 gm/cm³) contribute only 0.63% to overall analysis error for the test example. Therefore, normal field accuracy for brine density measurement is adequate for these procedures. Computed variation is shown in Table 3.

the first critical step in the analytical procedures is initial dilution of brine for analysis. A 5 cc aliquot is diluted to 25 cc in a volumetric flask. It is assumed that the analyst can correctly dilute to the 25 cc line in the volumetric flask. The major error is the dilution step will arise from brine clinging to the inside of the transfer pipet and from failure to remove the last drop from the pipet tip. This error is assumed to be a maximum of 0.20 cc out of a 5 cc aliquot, or 4% of the volume. The effect on analytical results is also 4%, as shown in Table 4.

The most error prone and sensitive step is pipetting the diluted brine into Erlenmeyer flask. A 1 cc aliquot is pipetted. An error of ± 0.05 cc is the maximum expected of a field analyst. This amount of error can make for serious inaccuracies in both cation and anion analyses. Error can be particularly large in bromide and zinc analyses in which the results are determined by difference. Table 5 shows that this size error in measurement can make $\pm 20\%$ error in the result for zinc and a $\pm 9.2\%$ error in the bromide result for the test example. It must be noted that a careful analyst can hold pipetting error to ± 0.01 cc by good technique and clean glassware. Under field conditions the level of error shown can be expected. The best way to minimize such error is by use of more dilute solutions; however, that practice would make the kit too cumbersome for field use.

TABLE 7 - Comparison of lab and field methods for several brines

	Brine Sample	wt% Ca ²⁺	wt% Zn ²⁺	wt% Cl ⁻	wt% Br ⁻	Mole ratio anions/ cations
Lab CaBr ₂	L	10.80	-----	-----	41.95	1.95
	K	11.03	-----	-----	42.71	1.94
Lab ZnBr ₂	L	-----	19.94	-----	49.68	2.04
	K	-----	19.75	-----	49.83	2.06
14.3 ppg	L	13.76	-----	11.72	28.67	2.00
Field	K	14.24	-----	13.66	28.15	2.08
	K	14.06	-----	12.53	30.08	2.06
11.4 CaCl ₂	L	12.78	-----	22.69	-----	2.01
Field	K	12.98	-----	23.08	-----	2.01
	K	13.24	-----	23.83	-----	2.03
11.7 CaCl ₂	L	13.75	-----	24.42	-----	2.01
Field	K	13.97	-----	24.94	-----	2.02
	K	14.64	-----	26.43	-----	2.04
16.4 ppg	L	9.51	7.37	7.22	40.75	2.04
Field	K	11.70	5.70	8.30	40.21	1.95
	K	10.88	6.63	8.41	40.09	1.98
15 ppg	L	9.12	5.84	6.19	35.81	1.97
Field	K	9.82	6.00	7.32	35.32	1.93
15.7 ppg	L	8.16	7.60	5.13	38.73	1.97
Field	K	7.31	7.66	4.97	37.93	2.05
Avg.	L	11.12	10.19	12.90	39.27	1.9988±0.033
	K	11.59	9.66	13.81	39.18	2.013±0.053

L = Lab analysis using standard wet chemical methods.

K = Field analysis using kit described here.

**TABLE 8 - Repeatability of sample analysis field kit,
single analysis 16 (ppg) brine**

Run No.	wt% Ca ²⁺	wt% Zn ²⁺	wt% Cl ⁻	wt% Br ⁻	Mole ratio anions to cations
1	12.40	4.6	9.0	38.6	1.947
2	12.3	4.7	8.9	38.9	1.947
3	12.2	4.6	8.7	38.8	1.947
4	12.4	4.6	9.1	38.4	1.942
5	12.2	4.6	8.9	38.5	1.952
Avg.	12.30	4.6	8.92	38.64	1.947
Std.					
Deviation	0.10	0.07	0.15	0.21	0.004

The last major source of error lies in detection of proper end point and in reading the buret after titrations and completed. An error of ± 0.2 cc is the estimated maximum that a field analyst should make. Table 6 shows effects of this size error on overall analysis. For the test case chosen, a 0.2 cc error contributes about 3% variation to the bromide and about 11% variation to the zinc analysis. As mentioned previously, these ions are determined by difference so that technique error are compounded.

Fortunately, it is unlikely that an analyst would make all errors tested here at the same time. The purpose of error sensitivity analysis is to highlight potential problem areas so that the analyst using the kit can be trained to use it most effectively.

KIT TESTING AND EVALUATION

A group of eight brines that had been previously analyzed by more precise lab methods were tested using the kit. Results are shown in Table 7. It can be seen that a careful analyst can get good results with the field kit. There is some variation in the results that may be due to a time lapse of a year or more between lab and kit analyses.

A further evaluation of the test kit involved multiple analysis of a single brine by an experienced analyst in the lab. A 16 ppg, three salt brine was analyzed five times starting with separate aliquots from the brine. Results of this evaluation, Table 8, shows that the kit is capable of giving excellent precision. The most important factor in obtaining precise results is the analyst's skill.

Field evaluation of the kit was made using operators and service personnel in several brine plants. Two brines were analyzed by different personnel, chosen at random, who were given samples without identifying them as other than routine. Training of these people was done by an experienced field service person who had been trained by lab personnel. Brines were a 14.7 ppg $\text{CaCl}_2/\text{CaBr}_2$ mixture and a 16.1 ppg $\text{ZnBr}_2/\text{CaBr}_2/\text{CaCl}_2$ mixture. Results are shown in Table 9.

TABLE 9 - Field analysis using kit

Brine 1, 14.7 ppg

Operator	wt% Ca^{2+}	wt% Cl^-	wt% Br^-	wt% CaCl_2	wt% CaBr_2
A	15.93	10.76	33.80	16.84	42.28
B	14.61	10.41	32.36	16.29	40.48
C	15.25	9.18	35.94	14.37	44.96
D	14.90	10.25	32.20	16.05	40.90
E	14.40	9.60	34.10	15.00	42.70
Avg.	15.02	10.04	33.68	15.71	42.26

(Continued)

TABLE 9 - Field analysis using kit

Brine 2, 16.1 ppg

Operator	wt% Ca ²⁺	wt% Zn ²⁺	wt% Cl ⁻	wt% Br ⁻	wt% CaCl ₂	wt% CaBr ₂	wt% ZnBr ₂
A	8.50	9.50	4.97	42.89	7.77	24.60	320
B	----	----	7.09	40.20	11.09	22.46	3134
C	8.16	9.80	5.38	40.86	8.42	21.15	3375
D	8.10	9.00	4.90	40.80	7.70	23.50	3100
Avg.	8.25	9.43	5.58	41.19	8.74	22.93	320

Operator-to-operator variation is well within the expected precision for a field method of the complexity involved in this analysis. Experience with this kit has shown that field personnel can be readily trained in use of the kit and are able to obtain good results under field conditions.

CONCLUSIONS

The field analysis kit described here provides results of acceptable accuracy for most field operations. The most critical step in procedure is sampling the diluted brine to provide the test aliquot. Adequate training should minimize this problem.

ACKNOWLEDGMENTS

The authors thank the managements of their respective companies for permission to publish this article.

LITERATURE CITED

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³H. A. Laiunen, Chemical Analysis, McGraw-Hill, New York, p. 212, 1960.

⁴W. J. Blaedel and Meloche, V. W., Elementary Quantitative Analysis, Second Edition, Harper and Row, New York, p. 296, 1963.

RECOMMENDED PRACTICE STANDARD PROCEDURE FOR TESTING HEAVY BRINES

FORWARD

- A. This recommended practice is under the jurisdiction of the API Committee on Standardization of Drilling Fluid Materials.
- B. The purpose of this recommended practice is to provide standard procedures for the testing of heavy brines.
- C. Metric units have been used in this publication.
- D. Other publications under jurisdiction of this committee:
Sec 13A -- Specification of Oil-Well Drilling Fluid Materials.
Covers specifications and test procedures for barite, bentonite, and attapulgate clay.
RP13B -- Standard Procedure for Testing Drilling Fluids.

BRINE SAMPLE EVALUATION: PROCEDURE FOR DETERMINATION OF CLARITY

SECTION I INTRODUCTION

1.1 DEFINITION

CLARITY is a relative expression referring to the turbidity in a brine due to the presence of suspended insoluble or immiscible particulate matter.

1.2 DESCRIPTION AND SCOPE

This procedure concerns standard methods for the evaluation of a representative sample of a clear brine. Concentration, particle size distribution, and type solids present may affect the utility of the brine. Minimum and/or maximum limit on contaminating solids is between the supplier and the user. Sampling of brines is complicated because of the possible presence of large particles of trash; the instability of certain dissolved ions, such as iron; and the overall influence of a variety of minerals, materials, and residues on brine quality. Fluids weighted with calcium carbonate or other weighing agents are excluded from this procedure.

Brine **CLARITY** is important in the following determination:

1.2.1 Formation damage potential.

1.2.2 Isolation of a source of contamination in the course of manufacture, transport, storage, or well site use.

1.2.3 Providing a basis for which specifications or limits can be placed on the concentration and/or type of solids found in water or brines.

1.3 OBJECTIVE AND LIMITATIONS

1.3.1 Objective--The primary objective of the test is to provide understanding and guidance on a method for the generation of a well-by-well calibration curve that relates turbidity by use of a nephelometer to solids concentration in a known density brine using the actual wellbore solids for a given well. Coarse matter greater than 200 mesh (74 microns) is excluded as a turbidity factor.

- 1.3.2 Limitations--The procedure recommended here can only place a relative value on the presence or absence of solids occurring in a particular sample. It should also be cautioned that in transferring brines from one tank to another or perhaps sampling during the course of several downhole displacements, the turbidity and type of solids will, in all probability, vary significantly from one sample to another. It is extremely important, therefore, to be aware of the actual event that a particular brine sample represents.

This procedure may not be applicable in the presence of fluid loss additives or thickeners.

In some cases, NTU (nephelometric turbidity units) values will be affected by color. Therefore, caution is advised in measuring turbidity.

SECTION II LABORATORY TESTING

2.1 EQUIPMENT AND MATERIALS NECESSARY TO GENERATE CALIBRATION CURVE

- 2.1.1 Samples of wellbore solids from the well to be completed. These may be obtained from the shale shaker or other appropriate places (500 mL).
- 2.1.2 Sample of clean completion brine (defined as "filtered") which will be used for the completion (2,000 mL).
- 2.1.3 47--mm, 1.2-micron membrane filter discs.
- 2.1.4 Forceps.
- 2.1.5 Analytical balance (± 1 mg).
- 2.1.6 Oven (drying oven $60^{\circ}\text{C} \pm 1$ C minimum).
- 2.1.7 Desiccator.
- 2.1.8 Fitted discs, funnels, vacuum flask, and funnel clamp.
- 2.1.9 Vacuum pump.
- 2.1.10 1-liter graduate.

- 2.1.11 Ten volumetric flasks (100 mL).
- 2.1.12 50-mL syringes.
- 2.1.13 Distilled water.
- 2.1.14 Petri dishes.
- 2.1.15 Turbidimeter (same unit used in this field)--a representative meter is shown in Figure 1.

The turbidimeter shall be of the nephelometer type and measure scattered light using two photo diodes each positioned at an angle of 90 degrees to the incident light beam. The source of light shall be a tungsten filament bulb operating at a color temperature of 2,000-3,000 degrees Kelvin.

The light path shall be perpendicular to the axis of the sample cuvette.

2.2 PROCEDURES

- 2.2.1 Shake the wellbore solid sample (2.1.1) until the sample is homogeneous.
- 2.2.2 Estimate the percent solid content by drying small amounts of sample in a Petri dish. (Weight of the dry sample divided by the wet sample would yield the approximate percent solids).
- 2.2.3 Make up 1,000 mL of stock solution (nonfiltered) using 1,000 mg of the wellbore solids (from 2.1.1) and the remainder volume with brine sample (from 2.1.2) in 1-liter graduate.
- 2.2.4 Make the following volumetric dilutions:

Dilution Ratio, Nonfiltered/ Filtered	Nonfiltered (mL)	Filtered* (mL)
0/100 baseline	0	100
25/75	25	75
50/50	50	50
75/25	75	25
100/0	100	0

*From 2.1.2

2.2.5 Measure turbidity (NTU) of each of the dilution samples and record.

2.2.6 Gravimetric analysis of dilution samples (run duplicates).

- Weigh ten predried 1.2-micron membrane filter discs and record the weights of each disc. (W_o).

- Insert one disc into filter equipment.

- Pass 100 mL of distilled water through the filter assembly to prewet the disc.

- Pass 100 mL of a dilution sample (2.2.4) through disc at 20 mL per time and record the volume (V_f) when no more volume will pass through. (If the samples contain high concentrations of solids (1,000 mg/L), it may be difficult to filter all of the 100 mL. In such cases, pass as much volume as possible and make a note).

- Pass 500 mL of distilled water through the disc. (If hydrocarbons are present in the brine sample, rinse with 500 mL of filtered Freon TF).

- Remove disc from filter equipment, and place in assigned Petri dish.

- Dry at 60°C for at least 1 hour, place in desiccator for 30 minutes, and weigh (W_i).

- Calculate the solids concentration in mg/L using sample calculation.

- Repeat the procedures for the five dilutions (2.2.4). Run duplicates at all five dilution levels.

2.2.7 Sample Calculation

Assume: $w_i = .010$ gms, $W_o = .002$ gms, and $V_f = 100$ ml

$$\begin{aligned} \text{Solids Concentration in mg/L} &= \frac{W_i - W_o \times 10^6}{V_f} \\ \frac{(.010 - .002) 10^6}{100} &= 80 \text{ mg/L} \end{aligned}$$

- 2.2.8 Plot NTU readings against mg/L. A straight line should be observed. The completed graph can be used to monitor changes in NTU value for a particular operation. (Examples are shown in figures 2 and 3.)

3.1 EQUIPMENT AND MATERIALS FOR FIELD TESTING

- 3.1.1 U.S. 200-mesh, woven sieve or API sand content set in good condition.
- 3.1.2 500-mL and 100-mL sample bottles (6-8).
- 3.1.3 Calibration curve (NTU versus mg/L) obtained in lab.
- 3.1.4 Nephelometer (2.1.15).
- 3.1.5 Graduated cylinder (100 mL).

3.2 PROCEDURE

3.2.1 Sampling Methods and Sampling Points.

Mixing Plants:

Fully circulated sample from the low-pressure line (no surface sampling).

Transport Operations:

Trucks--Flow at exit valve for about one-half of the volume of the load and then sample.

Supply Boats--Thief a sample before off-loading for use in density, clarity, and crystallization points tests.

Rig Site:

Specified Rig Tank--Sample at low-pressure line if available.

Flow Line.

Filtration Samples.

3.3 WELL SITE TURBIDITY TEST

- 3.3.1 Collect 100 mL of representative samples at the locations of interest (3.2.1).

- 3.3.2 Make an initial separation of the particle sizes in a brine by pouring 100 mL through a 200-mesh woven sieve (the screen in the API sand content kit may be used if desired) into a 100-mL graduated cylinder. Let stand for 2 to 5 minutes to allow solids to settle or float. (If no large solids present, no need to do this step). This procedure gives an indication of particle size and concentration present.
- 3.3.3 Scoop out floating solids. Pour the remaining sample containing dissolved and suspended solids in a sample bottle, being careful not to transfer coarse solids that have settled out.
- 3.3.4 Calibrate nephelometer using manufacturer's standards. For most nephelometers, sample size is 20 mL.
- 3.3.5 Measure the turbidity of collected samples (3.3.3).
- 3.3.6 Compare the NTUs to mg/L using the calibration curve from 2.2.8.

FIGURE 1
REPRESENTATIVE METER: SHABAN TURBIDIMETER

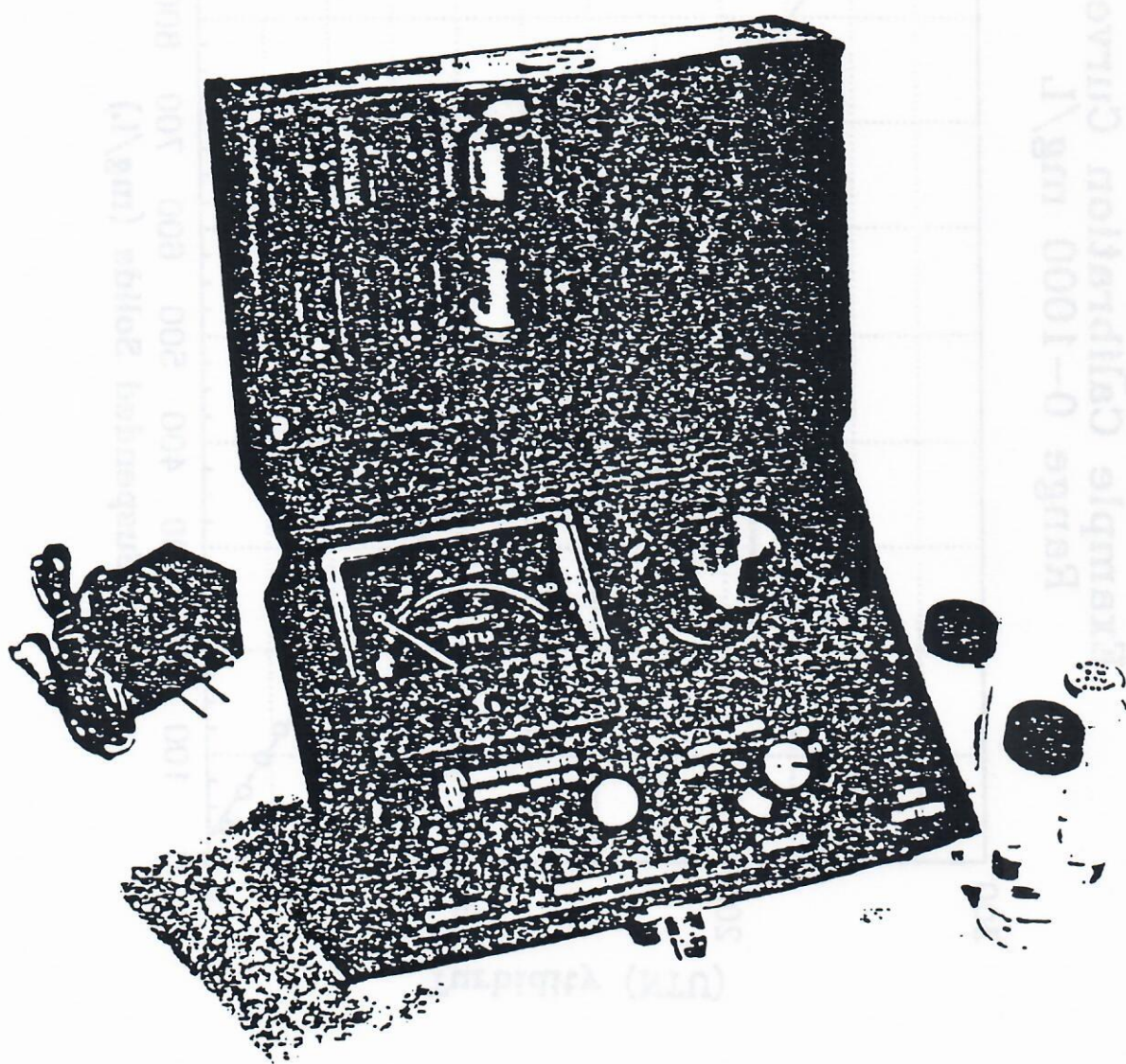
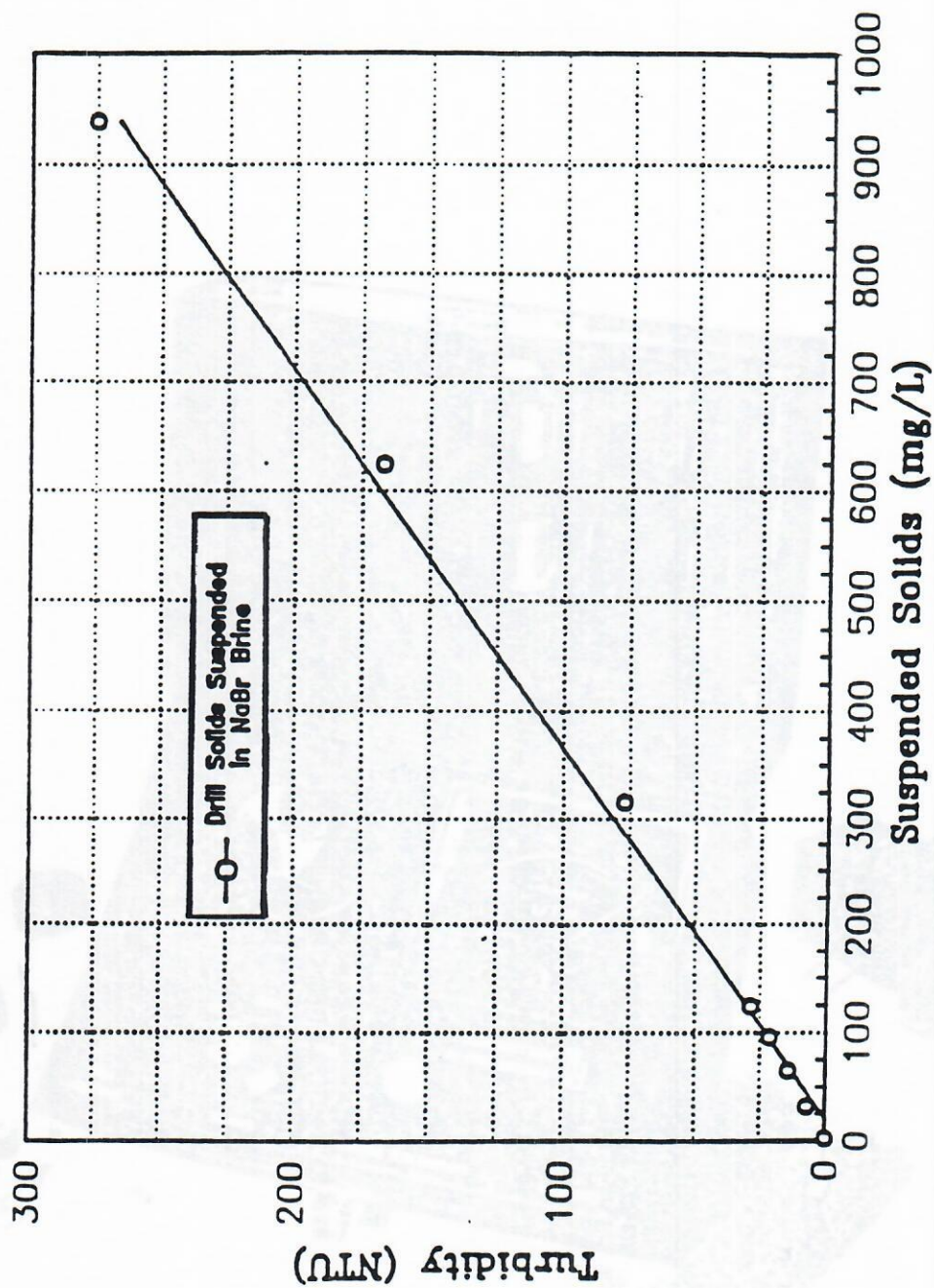


Figure 2
Example Calibration Curve
Range 0-1000 mg/L



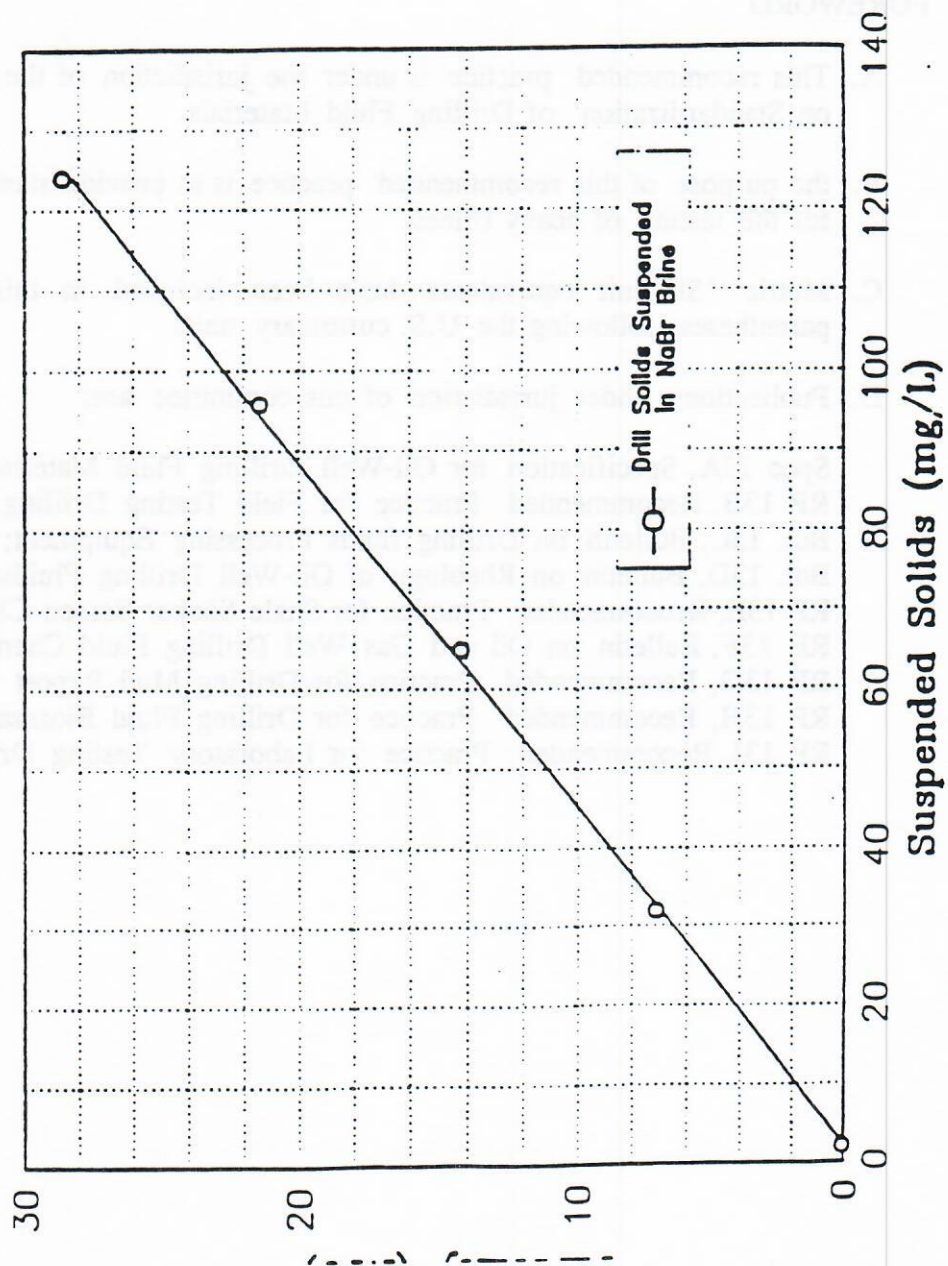
RECOMMENDED PRACTICE STANDARD PROCEDURE FOR TESTING HEAVY BRINES

FOREWORD

- A. This recommended practice is under the jurisdiction of the API Committee on Standardization of Drilling Fluid Materials.
- B. the purpose of this recommended practice is to provide standard procedures for the testing of heavy brines.
- C. Metric "SI" unit equivalents have been included in this publication in parentheses following the U.S. customary units.
- D. Publications under jurisdiction of this committee are:

Spec 13A, Specification for Oil-Well Drilling Fluid Materials;
RP 13B, Recommended Practice for Field Testing Drilling Fluids;
Bul. 13C, Bulletin on Drilling fluids Processing Equipment;
Bul. 13D, Bulletin on Rheology of Oil-Well Drilling Fluids;
RP 13E, Recommended Practice for Shale Shaker Screen Cloth Designation;
RE 13F, Bulletin on Oil and Gas Well Drilling Fluid Chemicals;
RP 13G, Recommended Practice for Drilling Mud Report Form;
RP 13H, Recommended Practice for Drilling Fluid Bioassays;
RP 13I, Recommended Practice for Laboratory Testing Drilling Fluids;

Figure 3
Example Calibration Curve
Range 0-140 mg/L



SECTION I

BRINE DENSITY

1.1 DESCRIPTION

- a. The composition of a brine (salt types and concentrations) determines its density. The density of brine, in turn, determines the hydrostatic pressure that a column of brine exerts downhole.
- b. The density of the brine is the mass of brine per unit volume. Density may be measured as pounds mass per gallon, pounds mass per cubic foot, or grams per cubic centimeter. Density may also be expressed in terms of specific gravity or pressure gradient. Specific gravity is the mass of a fluid at a given temperature relative to the mass of an equal volume of water at the same temperature. The pressure gradient is the hydrostatic pressure applied by the fluid per unit of vertical depth.
- c. The reference temperature for heavy brines in density versus composition tables is 70°F (21.1°C). Brine densities decrease with increasing temperature. The amount of decrease depends on the brine composition. By way of example, and 11.60 lb/gal (1390 kg/m³, or 1.390 g/cm³) CaCl₂ brine at 70°F (21.1°C) decreases to 11.57 lb/gal (1386 kg/m³, or 1.386 g/cm³) at 80°F (26.7°C).
- d. The measurement of density of brines will be affected by entrapped gases. If gas entrainment is a problem, one can use the procedures outlined in API RP 13B, Appendix D, for drilling fluids. These procedures use a pressurized mud balance or deaerator to measure density.
- e. Any instrument of sufficient accuracy to permit measurement within ± 0.05 lb/gal and reportable to within ± 0.1 lb/gal or ± 0.5 lb/ft³ (± 10 kg/m³, or ± 0.01 g/cm³) may be used. Two instruments are in general use in the field: mud balance and hydrometer.

MUD BALANCE

1.2 EQUIPMENT

The mud balance (Fig. 1.1 and 1.2) is a simple counterweight instrument. The weight of a mud cup filled with brine attached to one end of the beam is balanced on the other end by a fixed counterweight and a rider free to

move along a graduated scale. A level is mounted on the beam. Attachments for extending the range of the balance may be used.

1.3 PROCEDURE

- a. The mud balance base should be set up approximately level.
- b. Fill the clean, dry cup with brine to be tested. Put on and rotate the cap until firmly seated. Make sure some of the brine is expelled through the hole in the cap to free trapped air or gas.
- c. Wash or wipe the brine from the outside of the cup.
- d. Place the beam on the support and balance it by moving the rider along the graduated scale. The beam is horizontal when the bubble is on the center line.
- e. Read the density at the side of the rider toward the knife edge. Make appropriate corrections when a range extender is used.

1.4 PROCEDURE-CALIBRATION

The instrument should be calibrated frequently with fresh water. Fresh water should give a reading of 8.33 lb/gal or 62.3 lb/ft³, (998 kg/m³, or 0.998 g/cm³) at 70°F (21°C). If it does not, adjust the balancing screw or the amount of lead shot in the well at the end of the graduated arm as required.

1.5 CALCULATION

- a. Report the density to the nearest 0.1 lb/gal or 0.5 lb/ft³ (10 kg/m³, or 0.01 g/cm³).
- b. To convert the reading to other units, use the following:

$$(a) \quad \text{Density, g/cm}^3 = \frac{\text{lb/ft}^3}{62.43} = \frac{\text{lb/gal}}{8.34}$$

$$(b) \quad \text{kg/m}^3 = 16.02 (\text{lb/ft}^3) = 119.8 (\text{lb/gal}) = 1000 \text{ g/cm}^3$$

$$(c) \quad \text{Mud gradient} = \frac{\text{lb/ft}^3}{144}, \frac{\text{lb/gal}}{19.24}, \frac{\text{kg/m}^3}{2309}, \text{ or } \frac{\text{g/cm}^3}{2.31}$$

HYDROMETER

1.6 EQUIPMENT

- a. A set of glass hydrometers covering the range of specific gravities encountered in heavy brine applications. Graduations should be in specific gravity units (dimensionless) not greater than 0.002.

Note: 1. The hydrometer is a weighted bulb with a graduated stem. The depth to which the hydrometer sinks in a fluid is determined by the density in the fluid. The specific gravity is read directly from the graduated stem. Any oil present in the sample will interfere with determination; therefore, only fresh filtered samples should be used.

2. Although hydrometers with built-in thermometers may be used, it is recommended that the sample be brought to °C to avoid conversion errors.

- b. Cylindrical sample containers of clear glass or plastic. For convenience in pouring, the cylinder may have a lip on the rim. The inside diameter of the cylinder shall be at least in. cm. greater than the outside diameter of the hydrometer used. The height of the cylinder shall be such that the hydrometer floats in the sample with at least in. (2.5 cm.) clearance between the bottom of the hydrometer and the bottom of the cylinder.

- c. Thermometer - $32-220^{\circ}\text{F} + 2$ ($0-105^{\circ}\text{C} + 1$)

Note: Temperature of the brine measurement should be 70°F (21°C). If any other temperature must be used due to local conditions, appropriate corrections shall be made.

- d. Water bath regulated to $70^{\circ}\text{F} + 1$ ($^{\circ}\text{C} + 1$)

1.7 PROCEDURE

- a. Pour the sample into the clean sample container without splashing so as to avoid formation of air bubbles. Remove any air bubbles adhering to the surface by touching them with a piece of clean filter paper.
- b. Select a location that is free from wind or air currents.
- c. Place the hydrometer vertically in the brine contained by the sample cylinder.

- d. After the hydrometer has come to rest and floats freely away from the walls of the cylinder, read the specific gravity as the point at which the surface of the sample apparently cuts the hydrometer scale.
- e. Determine the temperature of the sample just after reading the hydrometer.

1.8 PROCEDURE - CORRECTION TO 70°F (21°C)

The specific gravity should be corrected to 70°F (21°C) if measured at some other temperature. This correction differs for different brines in different density ranges.

Note: Correction factors can be obtained from brine service companies and suppliers. The correction procedure is also discussed in Petroleum Engineering International (August 1983), pp. 80-96.

1.9 PROCEDURE - CALIBRATION

The set of hydrometers in use may be calibrated with a series of brines on known density.

1.10 CALCULATION

- a. Report the brine density to the nearest 0.1 lb/gal or 0.5 lb/ft³ or 0.01 g/cm³.
- b. To convert to other units, use the following:
 - (d) $\text{g/cm}^3, \text{ brine} = (\text{specific gravity}) (\text{g/cm}^3, \text{ water})$
 where density of water at 70°F (21°C) = 0.998 g/cm³
 - (e) $\text{Density, g/cm}^3 = \frac{\text{lb/ft}^3}{62.43} = \frac{\text{lb/gal}}{8.345}$
 - (f) $\text{Mud gradient, psi/ft} = \frac{\text{lb/ft}^3}{144}, \frac{\text{lb/gal}}{19.24}, \frac{\text{kg/m}^3}{2309}, \text{ or } \text{g/cm}^3$

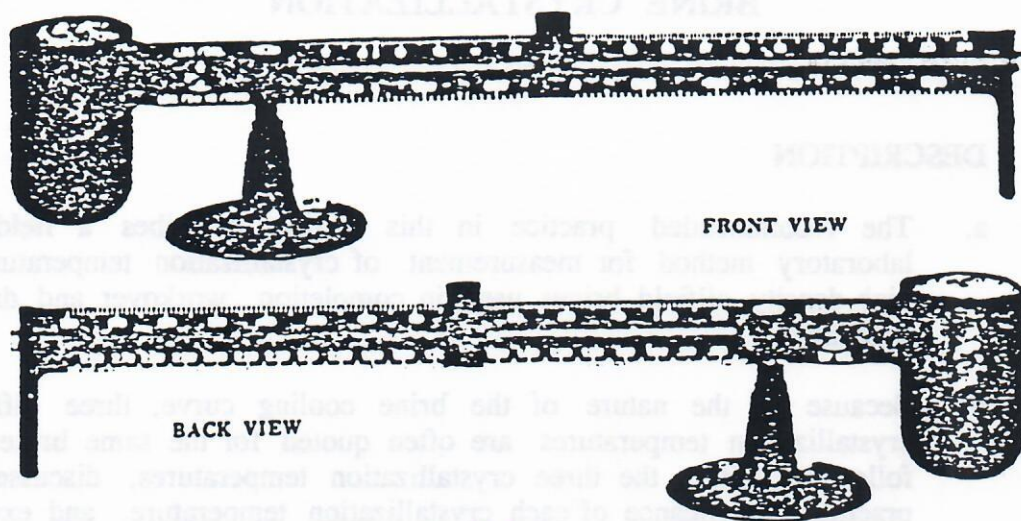


FIG. 1.1
MUD BALANCE

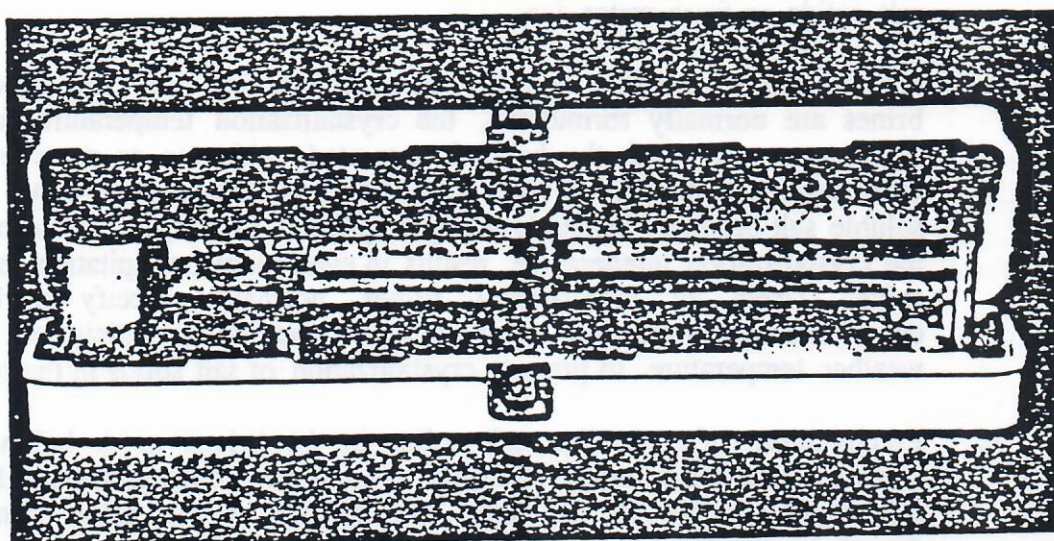


FIG. 1.2
MUD BALANCE AND CASE

SECTION II

BRINE CRYSTALLIZATION

2.1 DESCRIPTION

- a. The recommended practice in this section describes a field and laboratory method for measurement of crystallization temperature of high-density oilfield brines used in completion, workover and drilling operations.
- b. Because of the nature of the brine cooling curve, three different crystallization temperatures are often quoted for the same brine. The following defines the three crystallization temperatures, discusses the practical significance of each crystallization temperature, and explains the difference between crystallization of salt solids from a concentrated brine and freezing of water from a dilute brine.
- c. The actual crystallization temperature of a clear brine is that temperature at which a solid will begin to fall out of solution, if given enough time and proper nucleating conditions. The solid can be either salt solids or fresh-water ice.
- d. As high-density calcium chloride, calcium bromide, and zinc bromide brines are normally formulated, the crystallization temperature is the temperature at which the brine is saturated with one or more of the salts that it contains. At this crystallization temperature, the least soluble salt becomes insoluble and precipitates. Cooling the brine below the crystallization temperature results in even more precipitation of salt solids. Users of high-density brines normally specify a brine crystallization temperature near or below the lowest anticipated cold weather temperature to prevent crystallization of salt solids in the brine.
- e. Precipitation of crystalline salt solids in the brines at or below the crystallization temperature can lead to a number of rig problems. If the salt crystals settle in the tank, the density of the brine pumped downhole may be too low to contain formation pressures. As more and more salt crystals form, brine viscosity increases. The viscosity can become so high that the brine appears to be frozen solid. Lines are plugged, fluid in the tanks turns solid, and pumps seize. Reheating the brine redissolves these crystals with no permanent change in the brine properties.

- f. Since salt crystals are more dense than the brine, the brine will shrink in volume during crystallization, and there will be no rupturing of lines, valves or pump heads which can occur when water freezes.
- g. The crystallization temperature of a heavy brine at a given density can be varied by adjusting the concentration of the different salts in the system. Consequently, brines of a given density may be formulated with numerous crystallization temperatures. The lower crystallization temperature brines, as a rule, will be more costly to achieve. As a result, design of a brine with excessively low crystallization temperature can increase the cost of the fluid very significantly. A cheaper high-density brine with too high a crystallization temperature, on the other hand, can increase costs due to lost rig time from crystallization of the fluid in the pump, lines and storage tanks.
- h. With dilute oil-field brines such as sea water, calcium chloride solutions below 30%, and potassium chloride solutions below 20%, the salt dissolved in the water depresses the crystallization temperature or freezing point of the brine. That is, the temperature at which fresh-water ice starts to freeze out of solution is reduced by dissolved salt.
- i. Figure 2.1 shows the crystallization temperature of calcium chloride solutions as a function of concentration. The crystallization temperature of the brine decreases to as low as -59°F (-51°C) at a concentration of 30% calcium chloride (10.8 lb./gal density). In this portion of the curve, temperatures below the crystallization temperature result in the formation of fresh-water ice as in icebergs. Water freezes out of solution, producing a brine with higher salt concentration.
- j. At concentrations above 30% calcium chloride, the crystallization temperature of the brine starts to increase. This portion of the curve represents the solubility limit of calcium chloride in water. The crystallization temperature increases with increasing calcium chloride concentration because calcium chloride becomes insoluble at these high concentrations.
- k. There is another way of looking at the right-hand portion of the curve in Figure 2.1. As the temperature of the brine decreases, the calcium chloride becomes less soluble. Hydrated calcium chloride salts drop out of solution, producing a brine with a reduced salt concentration or lower density. This is the crystallization phenomenon that is used to test for the crystallization temperature of a high-density brine.
- l. All experimental methods for measuring the crystallization temperature of brine involve alternately cooling and heating a sample of the brine. Figure 2.2 is a representative cooling curve for a high-density brine.

Measured temperature of the cooling brine is plotted with time while the brine is alternately cooled and heated. Three experimental measures of crystallization temperature are delineated on Figure 2.2. These values for crystallization temperature are defined as follows:

1. FCTA (First Crystal to Appear): The temperature corresponding to a minimum in a plot of temperature during cooling or the temperature at which visible crystals start to form. FCTA will generally include some supercooling effect (cooling below actual crystallization temperature).
 2. TCT (True Crystallization Temperature): In a plot of temperature during a cooling cycle, the maximum temperature reached following the supercooling minimum, or the inflection point in cases with no supercooling.
 3. LCTD (Last Crystal to Dissolve): In a heating cycle, the temperature at which crystals disappear or the inflection point on the heating curve.
- m. TCT is the measured crystallization temperature nearest the temperature at which a brine will crystallize in tanks, pumps or transfer lines in the field. The cooling rate will be slow from the cool air. Also, the large brine volumes and high surface area in contact with the brine will provide abundant nucleation sites to prevent supercooling.
- n. The accuracy of the crystallization temperature methods depends on several factors, the most important of which is the control of supercooling. Supercooling can be minimized by slow cooling rates and nucleation of crystallization with selected solid surfaces.
- o. When a brine is cooled below its actual crystallization temperature, crystals may not form spontaneously because of lack of nucleation sites. This is the supercooling effect. Investigators have found that barium oxide, barium hydroxide, and bentonite are nucleators for high density brines; that is, a very small amount of these materials added to brines reduces the amount of supercooling.
- p. As crystals start to form at the FCTA, the heat released by the heat of crystallization increases the temperature of the sample. At the time, the formation of solids (hydrated salts) lowers the concentration of salt in the remaining brine. The temperature stops increasing when it reaches the crystallization temperature of the fluid remaining at that point, not the crystallization temperature of the original sample.

- q. Thus, the maximum temperature following supercooling is the actual crystallization temperature of the fluid remaining at that point, not the True Crystallization Temperature (TCT) of the original sample. If significant supercooling occurs (i.e., if TCT exceeds FCTA by 5°F (3°C) or more) the measurements should be repeated at a slower cooling rate. Investigators have found that samples that supercool on the first cycle often do not supercool on subsequent cycles.
- r. The heat of crystallization is also responsible for the inflection point at LCTD that can be observed as a crystallized solution is warmed. As the solution is heated, crystals absorb more thermal energy than the dissolved salts, thus slowing the warming rate of the solution. When all the crystals have dissolved at LCTD, the brine will warm more rapidly.
- s. When measuring the crystallization temperature of heavy brines, one has to be aware that minor components might come out of solution before the True Crystallization Temperature. For example, both sodium chloride and potassium chloride are less soluble than calcium chloride, calcium bromide, or zinc bromide. Therefore, if a heavy brine is contaminated with sodium chloride, the small amount of sodium chloride might drop out of solution and turn the brine cloudy at a temperature much higher than the TCT. If this sodium chloride is truly a minor component, it would not produce rig problems of the type mentioned above. Reformation of the heavy brine to reduce the faulty TCT could prove very expensive.
- t. In summary, the best of crystallization temperature of a brine is the TCT. This measured crystallization temperature best represents the temperature at which crystals will form a heavy brine on location. FCTA and LCTD may also be specified. FCTA will generally be lower than TCT, and LCTD will generally be higher than TCT. The difference between FCTA and TCT represents the degree of supercooling. If this difference exceeds 5°F (3°C), the TCT measurement should be re-made at a slower cooling rate.

2.2 EQUIPMENT

A typical crystallization temperature measurement set-up is shown in Figure 2.3. The following equipment is required to measure the crystallization temperature of a completion fluid:

- a. Digital thermometer with thermistor probe
Specifications: Indicating temperature range -50 to 100°F (-45 to 38°C)
minimum

Power Source: batteries, preferred

Readout: digital, preferred

Resolution: 0.1°F (0.05°C)

- b. Test tube: one 25 x 150 mm and one 20 x 150 mm
- c. Cooling bath: In order to limit supercooling, the cooling rate of the sample should not be too fast. Ideally this would mean a cooling rate no more than 1°F (0.5°C) per minute. From a practical standpoint, the cooling bath should be no more than 20°F (11°C) below that FCTA temperature. One or more of the following baths will be needed depending on the expected crystallization temperature:
 - 1. Ice/water slurry (50/50 vol/vol ice and water): use if FCTA temperature is above 35 to 40°F (2 to 5°C). Temperature of the bath will be 32°F (0°C).
 - 2. Ice/salt water slurry (50/50 vol/vol ice salt water; NaCl solution should contain 30 g NaCl in 90 cm³ water): Temperature should be approximately 5 to 10°F (-15 to -12°C). Use if FCTA temperature is about 10 to 40°F (-12 to 4°C).
 - 3. Antifreeze/water slurry (50/50 vol/vol antifreeze/water mixture). To cool the antifreeze/water bath, place the bath container inside a larger container which holds a dry ice-acetone bath. Cool to a temperature approximately 15°F (9°C) below FCTA temperature.
 - 4. Ice/CaCl₂ slurry (50/50 vol/vol ground ice and calcium chloride solution; CaCl₂ solution should contain 50 g CaCl₂ in 50 g water). This bath will provide temperatures down to -40°F (-40°C) as the ice melts.
- d. Seeding material: one tenth of one percent (0.1%) by weight of an inert, insoluble nucleating agent such as bentonite or barium oxide. (Use approximately 0.03 g, equivalent in volume to a pinch of salt, for 25 cm³ of the brine).

2.3 PROCEDURE

- a. Measure about 25 cm³ of the test fluid into the smaller (20 x 150 mm) test tube. Add the nucleating agent to the brine. Place the smaller tube containing the brine sample inside the larger test tube (25 x 150 mm) and immerse the tubes into the cooling bath with the thermometer probe inserted into the brine. (The thermometer probe also serves as the

stirring device). The purpose of the outside test tube is to moderate the rate of cooling of the brine in order to minimize supercooling.

- b. Stir the brine and watch the temperature decrease on the thermometer display. The temperature of the brine in the tube will decrease at a fairly steady rate until crystals form. Record the minimum temperature reached before crystallization as the FCTA point.
- c. The maximum temperature achieved immediately after crystallization has occurred should be recorded as the TCT. The temperature should stabilize at this temperature briefly (10-20 seconds). If it does not, or if large amounts of supercooling are evident (TCT minus FCTA greater than 5°F (3°C)), the test should be repeated using a cooling bath starting at a warmer initial temperature. If no supercooling has occurred, the temperature will remain constant briefly and the FCTA and TCT point will be the same temperature.
- d. Remove the tubes from the bath. Continue stirring and monitoring the temperature of the brine allowing it to warm. Watch for the dissolution of the crystals formed during the cooling cycle. When all crystals have dissolved, record the temperature of the brine in the tube as the LCTD temperature.
- e. The first cool/warm cycle may not yield results consistent with subsequent cycles. Repeat the procedure at least three more times during the same sample. Once an estimate of the TCT is known, the brine can be cooled rapidly to within 10°F (6°C) above the TCT by immersing the smaller test tube directly in the cooling bath. The test tube should then be placed within the second test tube to slow the cooling rate and minimize supercooling.
- f. Record the average of three runs, disregarding the first if it is inconsistent with the remaining data.

2.4 CALCULATION

Report the two or three temperatures for FCTA, TCT and LCTD.

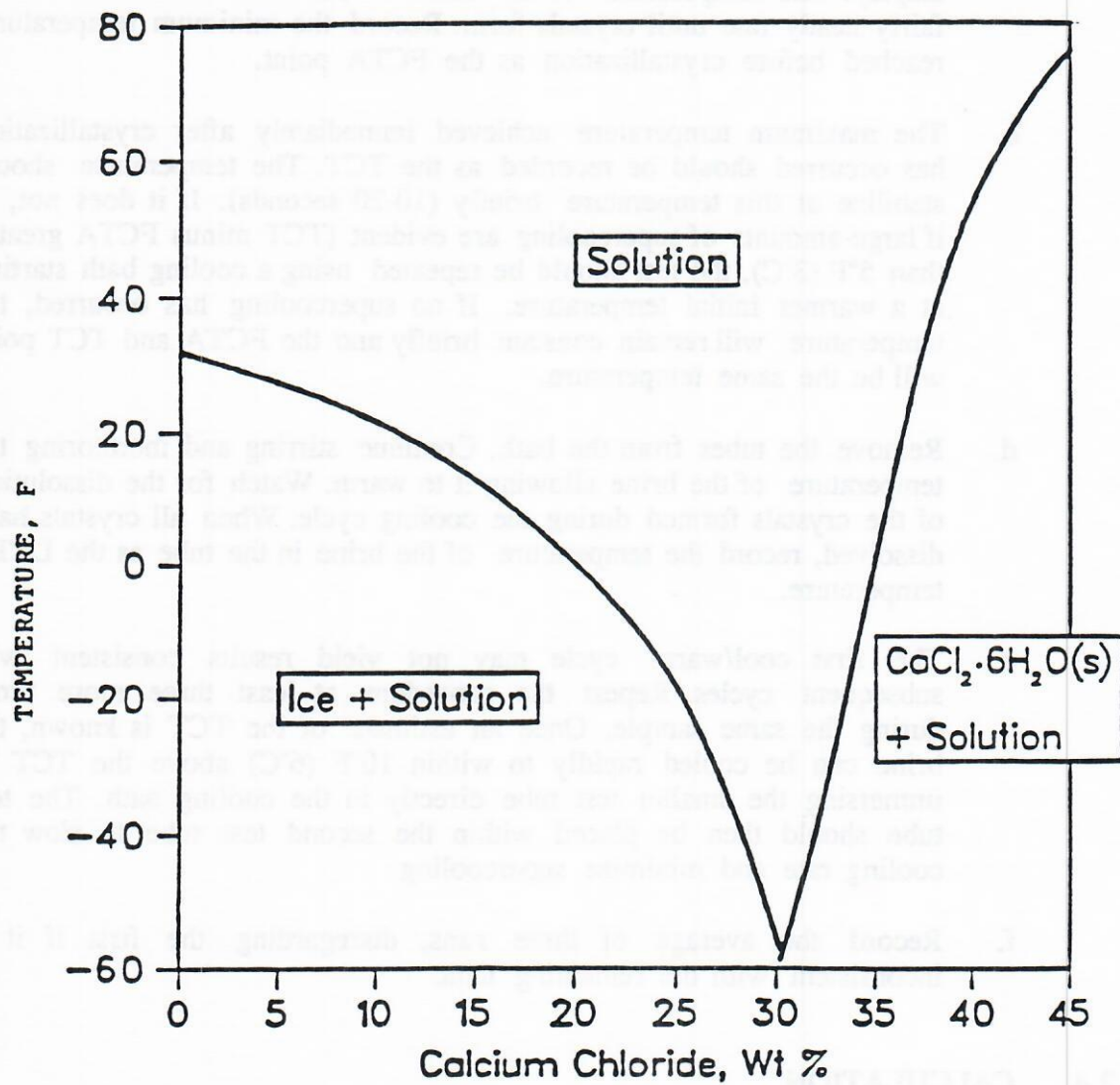


FIGURE 2.1
CRYSTALLIZATION TEMPERATURE OF
AQUEOUS CALCIUM CHLORIDE

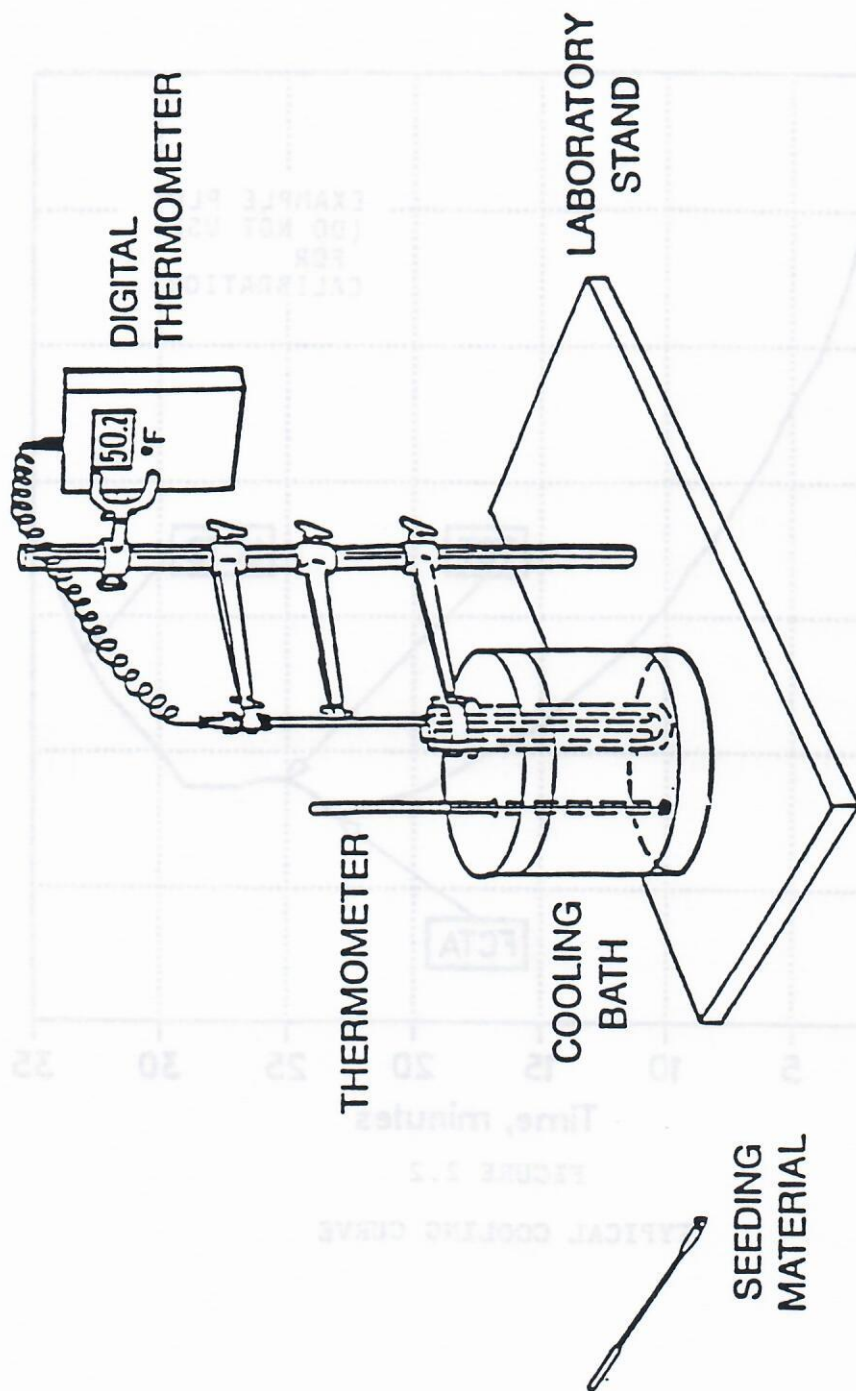


Figure 2.3
Design for Crystallization Temperature Measurements

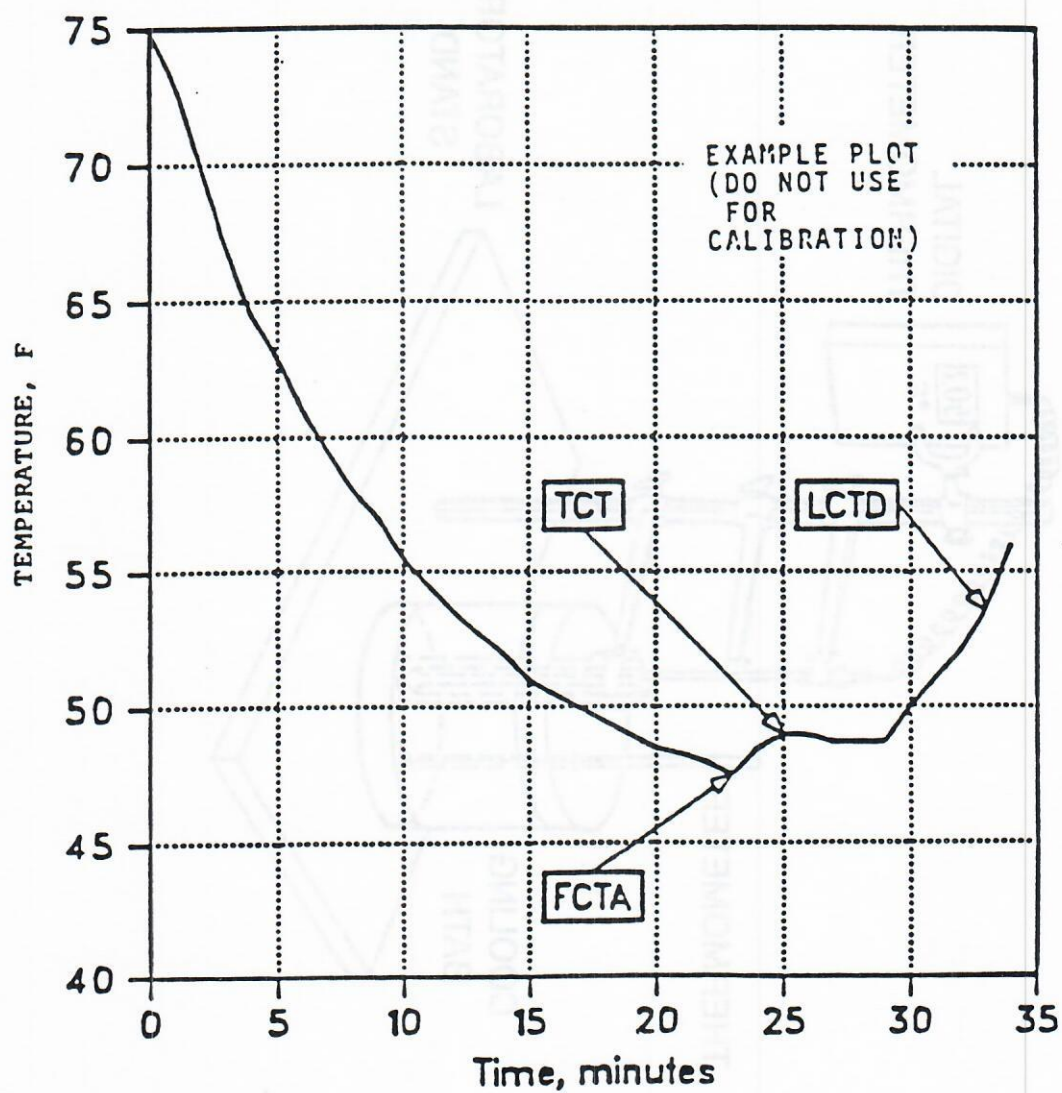


FIGURE 2.2
TYPICAL COOLING CURVE

SYNERGY FLUIDS

PRODUCT CODING

Products in the Synergy product line have a simple code to convey the function of the product.

Each product has a seven-digit code: AA XXXX B

AA - The first two letters designate the primary function of the product.

VI = Viscosifier

DF = Defoamer

VS = Viscosity and Suspension

WW = Well Wash

CI = Corrosion Inhibitor

BA = Bridging Agent

XXXX - The four-digit code, a number code, distinguishes different products that perform the same function. E.g., CI 1000 L is a general purpose liquid corrosion inhibitor suitable for most fluid applications. CI 2000 L is specially formulated for high temperature brine systems.

The four-digit number code may carry additional information about the product. For bridging agents, the number code gives an indication of the median particle size (in microns). E.g., BA 1005 S is calcium carbonate with a median particle size of 5 microns, BA 1150 S in calcium carbonate - median size 150 microns.

B - The last digit identifies the form of the product:

S = Solid

L = Liquid

E = Emulsion

D = Dispersion

SYNERGY FLUIDS

FUNCTION:

Viscosity Improver

GENERAL DESCRIPTION:

Hydroxyethyl Cellulose Dispersed (HEC)

PRODUCT CODE: VI 1000 S

PRODUCT BENEFITS:

- * Free-flowing powder
- * Disperses before solvation-easy to dissolve
- * Shear thinning but does not develop appreciable gel strength-easy solids removable.
- * Non-damaging to the formation
- * Most acid-soluble of polymer viscosifiers readily available
- * High molecular weight polymer - good thickening efficiency
- * Can viscosify brines in the 8.3-11.6ppg weight range

TYPICAL TREATMENT:

VI 1000 S is used in circulating systems in workover/completion and drilling operations. Typical concentrations are 1-3 pounds per barrel. Use clean equipment and mix slowly but thoroughly (no faster than 15 minutes per sack). VI 1000 S will disperse quickly and yield slowly. Allow time for the system to develop the full viscosity. Actual time will depend on the brine being used, consult your SYNERGY representative for his recommendations on your systems. Raising the temperature will improve the rate of viscosity build, do not raise the pH (heavy brines).

To maintain viscosity in a circulating system, it is better to frequently add small amounts of VI 1000 S than periodically add "slugs" of the product. Wetting VI 1000 S in diesel or non-toxic organic solvent will help disperse the polymer easily in the circulating system and minimize the formation of lumps or fish eyes.

For use in lost circulation pills, mix VI 1000 S (3-8 pounds per barrel) quickly with desired blend of bridging agents (BA 1000 S products) and pump the mixture downhole immediately. Do not wait for the viscosity to build.

In both circulating and pill situations, hydrochloric acid (HCl-15%) can be used to break the viscosity of VI 1000 S systems.

PRODUCT DESCRIPTION:

Color:	Cream/White
Odor:	None
Bulk Density:	28-40 lbs/ft ³
Shelf Life:	Indefinite
pH (2% Solution):	6-7
Activity:	99%
Packaging:	50# multiwall paper sacks
Storage:	Non-flammable, freeze/thaw stable
Acid Insoluble:	Less than 0.2% at 60°

RECOMMENDED USES:

VI 1000 S can be used to improve the viscosity of monovalent and divalent brines when these brines are typically used for hole cleaning, milling and reaming.

As the carrier in gravel packing operations

VI 1000 S can be used in lost circulation pills.

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheet MSDS
- * Additional technical information on the use of VI 1000 S in completion/workover and drilling applications
- * Technical information on acid solubility and viscosity breaking
- * Techniques for filtering viscosified brines
- * Information on predisposed liquid products (VI 1000 D) which minimize the waiting time for viscosity buildup and fracturing applications

SYNERGY FLUIDS

FUNCTION:

Viscosity Improver

GENERAL DESCRIPTION:

Hydroxyethyl Cellulose Dispersed
in an Organophilic Solvent

PRODUCT CODE: VI 1000 D

PRODUCT BENEFITS:

- * Rapidly builds viscosity at the surface
- * Does not "fish eye" upon mixing. Better more convenient, utilization of polymer content than similar solid products
- * Acid soluble
- * Simple to use, compatible with other completion/workover and drilling additives

TYPICAL TREATMENT:

For Brines:

VI 1000 D is added to a brine at the point of maximum mixing (mud hopper or through the jets). When added quickly, VI 1000 D will rapidly disperse and build viscosity without causing "fish eyes". Expect to use 103 ppb in normal applications.

When using VI 1000 D in a pill add the contents at the point of maximum mixing and pump down hole immediately.

For Drilling Fluids:

The basic components in VI 1000 D are non-toxic and non-ionic. VI 1000 D will not cause sloughing or increase dispersion of clays. It is compatible with all drilling fluid additives.

PRODUCT DESCRIPTION:

Color:	Tan to light brown
Odor:	Aromatic
Carrier:	Mineral Oil
Density:	9.3 lbs/gal
pH (1% Solution):	7.0
Packaging:	5 gallon cans
Storage:	Solvents are combustible, consult local codes. Contents will thicken in cold weather.

RECOMMENDED USES:

- * In brines to provide viscosity for hole cleaning and seepage control
- * In milling and underreaming to clean the hole
- * In gravel packing as an agent to control packing rates
- * In drilling fluids to provide viscosity in fresh and salt waters
- * In water-well drilling and seismic operations to provide rapid, convenient viscosity. There are no hazardous materials in VI 1000 D.

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheets, MSDS
- * Additional technical information on rheological properties, acid solubility, etc.
- * Techniques for filtering viscosified brines
- * Information on other predispersed products VI 2000 D, VS 1000 D, for use in a range of applications

SYNERGY FLUIDS

FUNCTION:

Viscosity Improver

GENERAL DESCRIPTION:

Dispersed HEC, preactivated
in an Organophilic Solvent

PRODUCT CODE: VI 2100 D

PRODUCT BENEFITS:

- * Quickly builds viscosity at the surface
- * Does not "fish eye" upon mixing
- * Acid-soluble
- * Useful over a broad range of brine compositions; chlorides and bromides, calcium and zinc salts
- * Does not contain clay or any other inorganic solids - compatible with true "solids free" systems

TYPICAL TREATMENT:

VI 2100 D is typically used in small pills where solids free heavy brines are needed. It can be used to reduce seepage losses to the formation, particularly during and after perforating.

VI 2100 D in a drill-in situation will reduce fluid losses, with or without calcium carbonate (BA 1000 S series). Expect to use 2-5 ppb VI 2100 D in both pills and circulating systems.

PRODUCT DESCRIPTION:

Color:	Tan
Odor:	Aliphatic
Density:	7.9 lbs/gal
pH (1% Solution):	7.0
Packaging:	5 gallon cans
Storage:	Flash point > 140°F

RECOMMENDED USES:

Calcium and zinc bromides and chlorides for rapid viscosity development at ambient temperatures

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheets, MSDS
- * Additional technical information, viscosities in different winter and summer blends, acid solubility, etc.
- * Information on other SYNERGY predispersed polymers for completion/workover fluids.

SYNERGY FLUIDS

FUNCTION:

Viscosity/Suspension Control

GENERAL DESCRIPTION:

Xanathan Gum

PRODUCT CODE: VS 1000 S

PRODUCT BENEFITS:

- * Dissolves in a wide range of brines
- * Provides improved rheological properties for brine fluids while also suspending calcium carbonate materials
- * Excellent temperature stability

TYPICAL TREATMENT:

VS 1000 S is used in circulating systems in workover/completions and drilling operations at 1-2 pounds per barrel. Equipment should be cleaned before use and the product added very slowly to the point of maximum agitation (at the mud hopper or through the jets). It is important to disperse each particle as quickly and efficiently as possible. Allow time for the viscosity to build. Raising the temperature will shorten the time to build full viscosity.

To maintain viscosity add small amounts of VS 1000 S frequently and slowly at the point of maximum agitation.

To suspend calcium carbonate in a pill, mix 2 to 4 pounds as quickly and as evenly as possible. Pump immediately without waiting for the viscosity to build.

15% HCl can be used to break VS 1000 S viscosity.

PRODUCT DESCRIPTION:

Color:	Creamy white powder
Odor:	None/slight acetic
Bulk Density:	52 lb/ft ³
Storage:	Non-flammable; freeze/thaw stable
Shelf Life:	> 6 months (powder)
pH (1% Solution):	5.0 - 6.5
Activity:	99%
Packaging:	50 lbs. multiwall paper sacks

RECOMMENDED USES:

VS 1000 S can be used in brines and drilling fluids to suspend calcium carbonate and improve rheological properties. Can be used in wells with BHT's up to 350°F. Can be used in circulating systems or in a pill.

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheets, MSDS
- * Additional technical information on rheological properties, acid solubility, viscosity breaking
- * Techniques for filtering viscosified brines
- * Information on the predispersed liquid product VS 1000 D which minimizes the waiting time for viscosity buildup

SYNERGY FLUIDS

FUNCTION:

Viscosity/Suspension Control

GENERAL DESCRIPTION:

Xanathan Gum dispersed in
an Organophilic Solvent

PRODUCT CODE: VS 1000 D

PRODUCT BENEFITS:

- * High molecular weight Xanathan Gum that disperses easily and hydrates rapidly in a wide range of brines
- * Does not contain weighting or bridging agents
- * Will provide viscosity and seepage control in conjunction with approved acid soluble solids
- * Non-damaging to the formation, good acid solubility characteristics

TYPICAL TREATMENT:

For Brines:

VS 1000 D will disperse quickly. Add at the point of maximum mixing (mud hopper or through jets). Treatment levels of 2-5 pounds per barrel can be expected for circulating systems.

Maintain the system with small treatments of VS 1000 D added frequently at the point of maximum mixing.

Expect to use 4-8 pounds per barrel VS 1000 D when building a pill for seepage control. Add the VS 1000 D at the point of maximum mixing and pump down hole immediately.

Drilling Fluids:

In drilling fluids VS 1000 D will provide viscosity and suspension control in fresh brackish and salt water. Application rate will vary from 0.5 to 5 pounds per barrel depending on the weight of the fluid.

PRODUCT DESCRIPTION:

Color:	Tan to light brown
Odor:	Aromatic
Density:	9.3 lbs/gal
pH (1% Solution):	6.0 - 7.0
Packaging:	5 gallon cans
Storage:	Solvents are combustible, consult local codes. Contents will thicken in cold weather

RECOMMENDED USES:

In brines to suspend bridging agents both in circulating systems and in pills.

In drilling fluids in top hole drilling and in polymer drilling systems to aid in suspension and filtration control.

Has good thermal characteristics in both completion and drilling fluids. VS 1000 D can be used in wells with BHT's up to 325°F

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheets, MSDS
- * Additional technical information on rheological properties, acid solubility and viscosity breaking
- * Information on other dispersed polymer systems VS 2000 D, VI 1000 D and VI 2000 D

SYNERGY FLUIDS

FUNCTION:

Corrosion Inhibitor

GENERAL DESCRIPTION:

Blend of polyphosphates, quaternary ammoniumchloride and sulfite

PRODUCT CODE: CI 1000 L

PRODUCT BENEFITS:

- * CI 1000 L is an all purpose corrosion inhibitor for drilling, completion and workover fluids
- * CI 1000 L is an effective oxygen scavenger, will combat hydrogen sulfite and carbon dioxide corrossions and will sequester most scale forming compounds
- * Compatible with many fluid systems from freshwater to high brine concentrations

TYPICAL TREATMENT:

Typical treatment levels are 1 can (5 gal.) CI 1000 L per 100 bbls of fluid.

In circulating systems additional material will be needed for maintenance.

For fluid systems above 200°F increase dosage as appropriate.

PRODUCT DESCRIPTION:

Color:	Orange
Odor:	Sulfur dioxide
Density:	8.8 lbs/gal
Flash Point:	> 160°F
pH:	6.0 - 7.0
Packaging:	55 gallon drums

RECOMMENDED USES:

- * Recommended uses include packer fluids, workover fluids, freshwater and salt water drilling fluids.
- * If excessive H₂S present in the fluid (> 5 ppm)² use CI 3000 L.

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheets, MSDS
- * Technical information on CI 1000 L
- * Information on other corrosion inhibitors such as CI 2000 L and CI 3000 L specific for applications in heavy brines

SYNERGY FLUIDS

FUNCTION:

High temperature Corrosion
Inhibitor for brine systems

GENERAL DESCRIPTION:

Formulated Product -Inorganic
Inhibitor with polyphosphate
and quaternary compound

PRODUCT CODE: CI 2000 L

PRODUCT BENEFITS:

- * Compatible with chloride and bromide brines, calcium or zinc based systems. Completely soluble
- * Does not effect the rheological properties of the system
- * Non-damaging to the formation
- * Limits corrosion rate to very low levels at temperatures up to 400°F

RECOMMENDED USES:

Brine Packer fluid & completion fluids. Brine drill-in systems for the protection of tubular goods where bottom hole temperatures may reach 450°F

TYPICAL TREATMENT:

2 - 5 gallons per 1,000 gallons in Packer fluids.

Use an initial dose of 5 gallons per 1,000 gallons in circulating systems and maintain with approximately 2 gallons per 1,000 gallons every circulation.

Add through the hopper, or under maximum mixing conditions.

PRODUCT DESCRIPTION:

Color:	Clear
Density:	10.9 lbs/gal
Pour Point:	Around 30°F
Flash Point:	Greater than 220°F
Shelf Life:	Indefinite in original sealed container
pH:	6.0 - 7.0
Packaging:	55 gal polyethylene drum
Storage:	No special precautions
Handling:	Use plastic gloves and safety goggles, avoid contact with skin
<u>Caution:</u>	When mixed with strong acids or oxidizing agents or when burning, may generate toxic fumes. Wear appropriate breathing equipment

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheets, MSDS
- * Technical data on corrosion testing of CI 2000 L
- * Questions on your specific application
- * Information on other corrosion inhibitors CI 1000 L, CI 3000 L

SYNERGY FLUIDS

FUNCTION:

Corrosion Inhibitor for brines

GENERAL DESCRIPTION:

Quaternary Compound

PRODUCT CODE: CI 3000 L

PRODUCT BENEFITS:

- * Soluble in brines
- * Does not affect rheological properties
- * Protects tubular goods against H₂S, CO₂ and organic acids
- * Controls the growth of certain microorganisms

RECOMMENDED USES:

Packer fluids, workover and completion fluids up to moderate temperatures

Can also be used to combat aerobic and anaerobic bacteria

TYPICAL TREATMENT:

Feed 5 - 7 gallons per 100 bbls (55 gallons/1000 bbls) continuously to maintain an effective film. If microorganisms control is important slug with five times this dosage initially and maintain the system at 5 - 7 gallons per 100 bbls as above.

PRODUCT DESCRIPTION:

Color:	Amber
Odor:	Alcohol
Pour Points:	+ 7°F
Flash Point:	< 76°F
Density:	8.0 lbs.gal
pH:	7.0 - 8.0
Shelf Life:	Indefinite in original sealed container
Storage:	Material is flammable, store appropriately
Handling:	Wear protective clothing, avoid contact with skin and eyes
Disposal:	Product is toxic; dispose of according to local, state and federal codes.

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheet, MSDS
- * Questions on your specific application
- * Information on other corrosion inhibitors CI 1000 L, CI 2000 L

SYNERGY FLUIDS

FUNCTION:
Defoamer

GENERAL DESCRIPTION:
White Fluid Emulsion

PRODUCT CODE: DF 1000 E

PRODUCT BENEFITS:

- * Effective over a broad pH range (2-11)
- * Economical and efficient
- * Formulated for freshwater, sea water, and calcium muds. Has good performance in brine/HEC systems
- * Compatible with most systems and additives

RECOMMENDED USES:

- * Sodium chloride, potassium chloride systems, clear brine fluids
- * AS with all foaming problems, pilot testing is recommended, both to establish the preferred defoamer and to optimize the loading

PRODUCT DESCRIPTION:

Color:	White emulsion
Density:	8.2 lbs.gal
pH:	8.2
Storage:	Protect from freezing
Packaging:	5 gallon cans

TYPICAL TREATMENT:

- * Good results have been obtained with loadings of 1 -2 gallons per 100 barrels of fluid

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheet, MSDS
- * Additional technical information on DF 1000 E
- * Information on other defoamers, DF 2000 L

SYNERGY FLUIDS

FUNCTION:

Defoamer

GENERAL DESCRIPTION:

Mixture of non-ionic surfactants

PRODUCT CODE: DF 2000 L

PRODUCT BENEFITS:

- * Easy to mix, requires no special equipment
- * Works well in a variety of fluid systems through to 19.2 ppg Zinc Bromide
- * Effective in solids-free and solids-laden systems

TYPICAL TREATMENT:

1 - 3 gallons/100 bbls of fluid will reduce air entrapment and surface foams in a wide variety of brines.

The same concentration or diluted out has been used to treat foams in drilling fluids.

PRODUCT DESCRIPTION:

Color:	Colorless liquid
Odor:	Characteristic
Density:	7.3 lbs/gal
Flash Point:	> 200°F
Packaging:	5 gallon containers
Storage:	Indefinite

RECOMMENDED USES:

To eliminate foaming caused by air entrapment or pure surface foams.

DF 2000 L has been designed to be effective in a broad range of brines, including zinc brines to 19.2 ppg. It is also an excellent freshwater defoamer.

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheet, MSDS
- * Additional technical information on DF 2000 L
- * Information on other defoaming products, DF 1000 E

SYNERGY FLUIDS

FUNCTION:

Flocculant

GENERAL DESCRIPTION:

Synthetic Polymer

PRODUCT CODE: WW 4000 L

PRODUCT BENEFITS:

- * Effective in freshwater, seawater, and produced brines
- * Works fast. Flocculates drilling fluid solids and cuttings instantaneously
- * Produces large stable flocs, easily removable with mud cleaner or other solids control equipment prior to or during filtration
- * Contains no soap or emulsifiers that would hydrate shale
- * WW 4000 L is non-damaging to formations when used in completion/workover fluids
- * Helps to clean downhole tools and equipment of drilling mud during displacement

RECOMMENDED USES:

Well wash to scavenge mud particles from casing, pipe and downhole tools during displacement. Flocculant of clay particles in brine fluids.

TYPICAL TREATMENT:

3/4% of Fluid Volume to be treated.

Add WW 4000 L directly into fluid with moderate agitation to adequately disperse product. Brine can be pretreated prior to displacement. Settling time of flocks - 5-30 minutes.

PRODUCT DESCRIPTION:

Color:	Blue
Density:	8.3 lbs.gal
Pour Point:	Around 30°F
Shelf Life:	Indefinite
pH:	7.0
Packaging:	5 gallon plastic pails

ADDITIONAL INFORMATION:

Contact your SYNERGY representative for:

- * Material Safety Data Sheet, MSDS
- * Questions on your specific application
- * Information on other Completion/Workover Fluid additives

WW 4000 L

GENERAL SPECIFICATIONS AND PROPERTIES

WW 4000 L is a complex blend of organic compounds exhibiting both nonionic and anionic properties. The blend is formulated in a solvent which meets combustible standards and is non-volatile. The active components of WW 4000 L are completely biodegradable. WW 4000 L displacement fluid additive is safe to dispose of offshore as well as treatment fluid. WW 4000 L displacement fluid additive possesses the following typical specifications:

DESCRIPTION AND APPLICATION

WW 4000 L is a displacement fluid additive that disperses solids and removes them from the well formation. WW 4000 L additive removes drilling mud, sand, oil, polymer and other debris from casing, drill pipe and associated surface equipment to prevent contamination of completion fluid.

WW 4000 L additive may be used for well stimulation as a result of unsuccessful well completions. WW 4000 L additive used for well stimulation removes well debris from prior completions. Treatments with WW 4000 L followed by the introduction of PI 1000 L (paraffin inhibitor/solvent and remedial oil-soluble surfactant) have proven to be a very effective system for well stimulation.

WW 4000 L displacement fluid additive was developed to create the proper conditions for dissociating solid particles and contaminating fluids from metallic surfaces and to retard their agglomeration and redeposition. Water treated with one percent by volume WW 4000 L additive produces a displacement fluid which when circulated through the wellbore and throughout all surface equipment, effectively removes solid particles from casing, drillpipe and surface equipment. The displacement fluid and entrained solids are then displaced by clean seawater which is circulated through the wellbore and surface equipment. The seawater is further displaced with the brine completion fluid. Freshwater may be used instead of seawater at land sites.

WW 4000 L applications in oil and gas wells with seawater and freshwater displacements, and displacement spacers, in both oil base and water base mud procedures, should prove successful. The use of WW 4000 L displacement fluid additive should result in either no required filtering or minimal filtering of calcium, potassium and sodium chloride and other brine completion fluids.

Displacement fluids containing WW 4000 L additive require no special equipment and can be effectively applied by rig personnel without technical assistance.

Seawater or Freshwater Displacement

Drilling mud should be displaced with seawater after the casing has been cemented and tested. Most of the mud solids are removed by circulating one or two times the hole capacity. After the seawater displacement, 200 to 1,000 barrels of seawater treated with WW 4000 L additive are circulated through the well, mud pits, pumps, lines and shale shakers.

1. Displace drilling mud from the well with seawater or freshwater at maximum circulating rate until the flowline water appears clean.
2. Clean all pits, lines, and surface equipment.
3. Add WW 4000 L displacement fluid additive through the rig hopper at one percent by volume or 1 drum per 130 barrels of water. Operate pit agitators and gun lines to assure adequate mixing. Thoroughly wash hopper after mixing.
4. Circulate the WW 4000 L additive and displacement fluid mixture throughout the entire surface system such as pumps, hopper, valves, shale shaker and degasser, down the drill pipe and up the annulus.
5. While circulating the displacement fluid mixture, reciprocate the pipe and occasionally rotate. For best performance, WW 4000 L mixture must be kept in turbulent flow.
6. Once the treatment has begun, do not interrupt circulation.
7. Dispose of the displacement fluid mixture as required after one or two complete circulations by displacing with clean untreated water. If clean water is not available, this step is not essential.
8. Displace with brine completion fluid. Be sure that the completion fluid from tankage is clean.

Oil Base Mud Displacement

1. Clean all pits, lines, and surface equipment.
2. Mix 22 barrels of oil mud flush, using 20 barrels of water plus 2 drums of the WW 4000 L additive.
3. Mix maximum allowable water pill with 1 to 2 percent WW 4000 L displacement fluid additive, with agitators and centrifugal pump circulating and agitating at maximum capacity through surface equipment.
4. Circulate the WW 4000 L additive and displacement fluid mixture pill in turbulent flow down through the drill pipe and up the annulus. Circulate with the drill pipe reciprocating and occasionally rotating.
5. Once the treatment has begun, do not interrupt circulation.
6. Dispose of the displacement fluid mixture as required after one or two complete circulations.
7. Displace with brine completion fluid. Be sure that the completion fluid from tankage is clean.
8. Take samples of completion fluid before pumping down the drill pipe and after it returns to the surface before filtering.

SAFETY AND HANDLING PRECAUTIONS

No special provisions for handling are required.

Ingredients may be harmful to humans. Do not take this product internally. If it is ingested, secure medical attention immediately. Avoid prolonged contact with skin to prevent irritation; may be absorbed by the skin. In case of contact with skin, wash well with soap and water. In case of contact with eyes, flush promptly and thoroughly with clear water and immediately secure medical attention. Wear rubber gloves, and goggles or face shield when handling.