

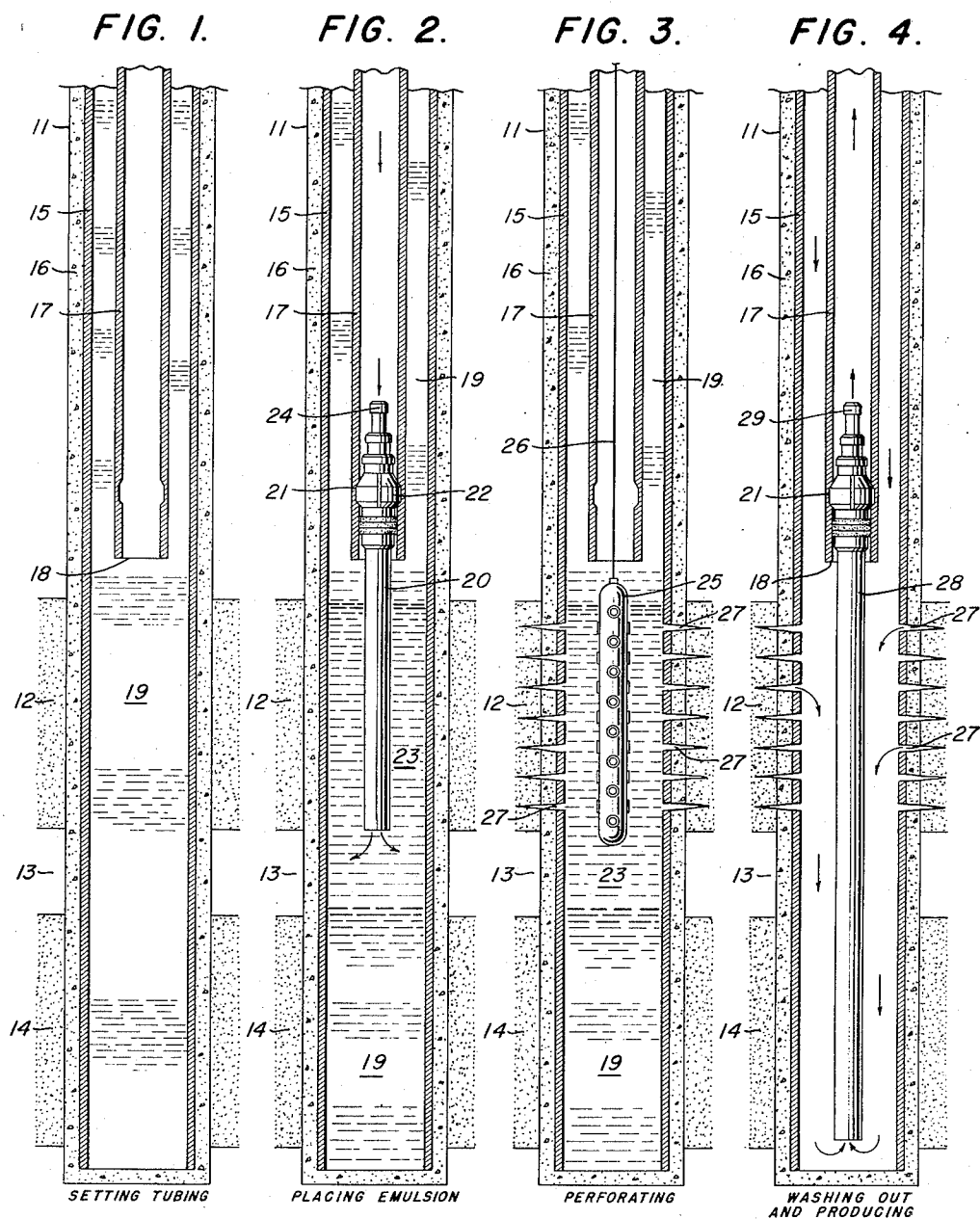
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PERFORATING WELLS

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PERFORATING WELLS

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The present invention is directed to a method for completing oil and gas wells. More particularly, the invention is directed to a method for completing oil and gas wells in which a drilling fluid or mud is used to control the well. In its more particular aspects, the invention is directed to a method for completing an oil or gas well in which a column of drilling mud is maintained in a casing to control the well.

Current practice when completing wells, such as oil and gas wells, through perforated casings is to have drilling fluids, such as mud, salt water, water, or oil, in the well casing and to perforate the casing with bullet, shaped charge, chemical or punch-type perforators. When the pressure of a formation traversed by the well exceeds the hydrostatic pressure of a column of oil or water at the completion depth, it is customary to use weighted salt water or normal drilling mud having a density great enough to exceed formation pressure in order to control the well while perforating the casing and performing other routine completion operations. In the case of a well filled with drilling mud when the casing is perforated, the drilling mud flows into the perforations because of the pressure differential existing between the interior of the casing and the formation. The perforations are thereby partially or completely plugged with mud and this plugging is aggravated by the heat and instantaneous pressure evolved by the propellant power in the case of bullet perforators and the high explosive in the case of the jet or shaped charge perforators. Where chemical or punch-type perforators are employed, it is not uncommon for the drilling mud to lose water rapidly to the formation resulting in the drilling mud becoming dehydrated and forming plugs. Data are available which indicate that such plugs whether formed by dehydration of the drilling mud by heat, and/or pressure or by loss of water to the formation are difficult to remove by subsequent flow from the formation into the well bore and that the productivity of a perforating interval in a producing formation is significantly reduced. Field completion attempts of wells indicate that such plugging of the perforations may cause formations to be tested as being non-productive and thereby condemned when actually the formation may contain economically producible oil or gas. Thus it is clear that the problem of plugging of perforations is serious and is a source of expense in well completions and of erroneous conclusions in exploratory work which may cause major hydrocarbon reserves to remain undiscovered.

Another problem which exists in perforating wells is that it is necessary to provide control of the well during

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perforations. This is accordingly accomplished by maintaining a hydrostatic column which exerts a pressure greater than the formation pressure exposed when the casing is perforated. However, to provide a column having a sufficient hydrostatic pressure, it is necessary to add weighting agents such as barite, sand, and other solid heavy materials to the fluid column maintained in the well.

In accordance with the present invention the problem of plugging perforations in a well casing in which a column of drilling mud is maintained to control the well is eliminated by providing in the well casing adjacent the producing formation a zone from which the drilling mud is removed or excluded and then perforating the casing in the zone such that the drilling mud does not plug the perforations.

The present invention may, therefore, be briefly described as involving the replacing or displacing of the drilling mud at least in the region of the formation to be penetrated with a solids-free emulsion of an oily and aqueous medium containing a soluble weighting agent dissolved in one of the components of the emulsion, the emulsion being characterized by having a low fluid loss into the formation and having the property of displacing the drilling mud from the region of the casing to be perforated.

The emulsion employed in the practice of the present invention is used in the sense of the emulsions described in Sutherland's "Introduction of Emulsions," Chemical Publishing Company, Inc., Brooklyn, New York, 1947, page 1 where an emulsion is described as follows: "Emulsions are intimate mixtures of two immiscible liquids, one of them being dispersed in the other in the form of fine droplets." The emulsion of the present invention contains, dissolved in one of the components of the emulsion, a weighting agent which is soluble in one of the components. The weighting agent may be soluble either in the aqueous phase or the oily phase of the emulsion. For example, the water phase may contain a water-soluble, inorganic weighting agent.

The oily phase may suitably be a hydrocarbon, such as crude petroleum and fractions thereof, such as gasoline, kerosene, gas oil, diesel oil, and the like. Other hydrocarbonaceous materials or derivatives of hydrocarbons, such as carbon tetrachloride and the like, may form all or part of the oily phase.

The emulsion may either be heavier or lighter than the drilling fluid and suitably may have a density in pounds per gallon in the range from about 7 to about 18 pounds per gallon. The emulsion where lighter than the drilling fluid may have a suitable viscosity sufficient to displace the drilling mud and to prevent displacement thereof by the drilling mud. For example, the viscosity of the emulsion replacing the drilling mud may range from about 10 to about 4000 centipoises at 60° F.

The emulsion of the present invention may suitably contain film-strengthening agents and emulsifying agents. As examples of the emulsifying agents may be mentioned sorbitan mono-oleate, sorbitan sesquioleate, polyoxyethylene esters of mixed fatty and resin acids, polyoxyethylene sorbitan mono-stearate, polyoxyethylene lauryl alcohol, sodium lignosulfonate, polyoxyethylene sorbitol tetraoleate, polyoxyethylene sorbitol monolaurate, and the like.

The film-strengthening agents may comprise a high molecular weight polymer or condensation product of sulfonated phenolformaldehyde, sodium carboxymethyl cellulose, guar flour, sodium lignosulfonate, and the like. There are many water-soluble, inorganic weighting agents which find use in the practice of the present invention among which may be mentioned, by way of illustration and not by way of limitation, alkali metal carbonates, alkali metal chlorides, zinc chloride, calcium chloride, barium chloride, ferric chloride, and the like. Potassium carbonate, zinc chloride, calcium chloride, and sodium chloride are particularly useful. Examples of the water-soluble inorganic weighting agents are presented in the following table:

TABLE I

Water soluble inorganic compounds suitable as weighting agents

Name	Formula	Specific Gravity
Aluminum bromide	AlBr ₃	3.01
Aluminum chloride	AlCl ₃	2.44
Aluminum iodide	AlI ₃	3.98
Ammonium bromide	NH ₄ Br	2.33
Ammonium iodide	NH ₄ I	2.51
Ammonium nitrate	NH ₄ NO ₃	1.72
Ammonium phosphate, dibasic	(NH ₄) ₂ HPO ₄	1.62
Antimony trichloride	SbCl ₃	3.14
Antimony trifluoride	SbF ₃	4.38
Barium acetate	Ba(C ₂ H ₃ O ₂) ₂	2.47
Barium bromide	BaBr ₂	4.78
Barium iodide dihydrate	BaI ₂ ·2H ₂ O	5.15
Barium iodide hexahydrate	BaI ₂ ·6H ₂ O	5.0
Barium nitrate	Ba(NO ₃) ₂	3.23
Cadmium acetate	Cd(C ₂ H ₃ O ₂) ₂	2.34
Cadmium bromate monohydrate	Cd(BrO ₃) ₂ ·H ₂ O	3.8
Cadmium bromide	CdBr ₂	5.2
Cadmium chloride	Cd(ClO ₃) ₂	2.3
Cadmium chlorate	CdCl ₂	4.05
Cadmium iodide	CdI ₂	5.67
Cadmium nitrate tetrahydrate	Cd(NO ₃) ₂ ·4H ₂ O	2.45
Cadmium sulfate heptahydrate	CdSO ₄ ·7H ₂ O	2.48
Calcium bromate monohydrate	Ca(BrO ₃) ₂ ·2H ₂ O	3.33
Calcium bromide	CaBr ₂	3.35
Calcium chloride	CaCl ₂	2.15
Calcium iodide	CaI ₂	3.96
Calcium nitrate	Ca(NO ₃) ₂	2.36
Cupric bromate hexahydrate	Cu(BrO ₃) ₂ ·6H ₂ O	2.58
Cupric bromide	CuBr ₂	2.8
Cupric chloride	CuCl ₂	3.05
Cupric nitrate hexahydrate	Cu(NO ₃) ₂ ·6H ₂ O	2.07
Ferric chloride	FeCl ₃	2.81
Ferric nitrate hexahydrate	Fe(NO ₃) ₃ ·6H ₂ O	1.68
Ferric sulfate monohydrate	Fe ₂ (SO ₄) ₃ ·H ₂ O	2.1
Ferrous bromide	FeBr ₂	4.64
Ferrous chloride	FeCl ₂	2.70
Lead acetate trihydrate	Pb(C ₂ H ₃ O ₂) ₂ ·3H ₂ O	2.55
Lead chlorate monohydrate	Pb(ClO ₃) ₂ ·H ₂ O	4.04
Lead nitrate	Pb(NO ₃) ₂	4.53
Lithium bromide	LiBr	3.46
Lithium iodide	LiI	4.06
Magnesium bromide	MgBr ₂	3.72
Magnesium iodide	MgI ₂	4.25
Manganese bromide	MnBr ₂	4.39
Manganese chloride tetrahydrate	MnCl ₂ ·4H ₂ O	2.01
Manganese iodide	MnI ₂	5.01
Nickel bromide	NiBr ₂	4.64
Nickel nitrate hexahydrate	Ni(NO ₃) ₂ ·6H ₂ O	2.05
Potassium acetate	KC ₂ H ₃ O ₂	1.8
Potassium carbonate	K ₂ CO ₃	2.29
Potassium fluoride	KF	2.48
Potassium iodide	KI	3.13
Potassium nitrite	KNO ₂	1.92
Potassium phosphate	K ₃ PO ₄	2.56
Sodium bisulfate	NaHSO ₄	2.74
Sodium bromide	NaBr	3.20
Sodium chlorate	NaClO ₃	2.49
Sodium chloride	NaCl	2.16
Sodium hydroxide	NaOH	2.13
Sodium iodide	NaI	3.67
Sodium nitrate	NaNO ₃	2.26
Sodium nitrite	NaNO ₂	2.17
Sodium phosphate monobasic	NaH ₂ PO ₄ ·2H ₂ O	1.91
Zinc bromide	ZnBr ₂	2.56
Zinc carbonate	ZnCO ₃	4.22
Zinc chloride	ZnCl ₂	2.91
Zinc iodide	ZnI ₂	4.66
Zinc nitrate hexahydrate	Zn(NO ₃) ₂ ·6H ₂ O	2.06
Zinc sulfate	ZnSO ₄	3.74

There are many oil-soluble organic weighting agents which are soluble in the oily phase of the emulsion employed in the practice of the present invention. The oil-soluble organic weighting agents suitably have a specific gravity in the range from about 1.2 to about 4. These organic weighting agents are illustrated in the following table:

TABLE II

Organic weighting agents

Name	Formula	Specific Gravity
m-Aminobenzoic acid	NH ₂ C ₆ H ₄ COOH	1.511
n-Amylbromide	CH ₃ (CH ₂) ₅ CH ₂ Br	1.218
iso-Amylbromide	(CH ₃) ₂ CH(CH ₂) ₃ Br	1.22
tert-Amylbromide	(CH ₃) ₃ C(Br)C ₂ H ₅	1.216
Amylbromide	(CH ₃) ₂ CCH ₂ Br	1.26
10 Amyliodide (n)	CH ₃ (CH ₂) ₅ CH ₂ I	1.51
iso-Amyliodide	(CH ₃) ₂ CHCH ₂ CH ₂ I	1.515
sec(n)-Amyliodide	C ₂ H ₅ CH(CH ₃)CH ₂ I	1.507
tert-Amyliodide	(CH ₃) ₃ CC ₂ H ₅ I	1.471
Amyliodide	C ₂ H ₅ CH(CH ₃)CH ₂ I	1.524
Anthracene	(C ₆ H ₄) ₂	1.25
15 Anthraquinone	(C ₆ H ₄) ₂ (CO) ₂	1.438
Asparagin	HO ₂ CCH(NH ₂)CH ₂ CONH ₂	1.54
Aspartic acid	C ₄ H ₇ O ₄ N	1.66
Benzal bromide	C ₆ H ₅ CH ₂ Br	1.51
Benzene hexa chloride	C ₆ H ₂ Cl ₆	1.89
Benzoic acid	C ₆ H ₅ CO ₂ H	1.266
Benzanilide	C ₆ H ₅ NHCOCC ₆ H ₅	1.31
Benzamide	C ₆ H ₅ CONH ₂	1.34
20 Benzylbromide	C ₆ H ₅ CH ₂ Br	1.44
Benzyl iodide	C ₆ H ₅ CH ₂ I	1.73
Bromal	Br ₂ CCHO	2.665
p-Bromacetanilide	BrC ₆ H ₄ NHCOCH ₃	1.77
Bromoacetophenone	C ₆ H ₅ COCH ₂ Br	1.65
p-Bromoaniline	BrC ₆ H ₄ NH ₂	1.80
Bromobenzene	BrC ₆ H ₅	1.495
Bromiodobenzene	BrC ₆ H ₄ I	2.257
25 Bromiodoethane (1,1)	CH ₃ CHBr ₂ I	2.45
1,2 Bromiodoethane	BrCH ₂ CH ₂ I	2.52
Bromiodomethane	BrCH ₂ I	2.96
Bromonaphthalene	C ₁₀ H ₇ Br	1.605
Bromosuccinic acid	HOOCCH ₂ CHBrCOOH	2.07
Bromotoluene (o)	BrC ₆ H ₄ CH ₃	1.422
Bromotoluene (m)	BrC ₆ H ₄ CH ₃	1.41
30 Bromotoluene (p)	BrC ₆ H ₄ CH ₃	1.39
Bromoforn	CHBr ₃	2.89
Butyliodide	C ₄ H ₉ CH ₂ CH ₂ I	1.617
Chlorobromobenzene	ClC ₆ H ₄ Br	1.63
Chlorodibromoethane	BrCH ₂ CHClBr	2.3
Chlorodiodomethane	ClCH ₂ I	3.17
Chlorodiodobenzene	ClC ₆ H ₄ I	1.95
Chloriodoethane	ClCH ₂ CH ₂ I	2.1
35 Chlorotetrabromoethane	Br ₂ CHClBr ₂	3.4
Chlorotribromoethane	BrCH ₂ ClBr ₂	2.6
Chlorotribromomethane	ClCBr ₃	2.7
Pentabromoethane	Br ₂ CHCBr ₃	3.4
Tetrabromoethane (sym)	Br ₂ CHCHBr ₂	2.96
Iodoform	CHI ₃	4.0
40 Ethylene Dibromide	BrC ₂ H ₄ Br	2.17

It is to be noted that, in all cases, the soluble weighting agents of Tables I and II have specific gravities greater than that of water.

The emulsion employed in the present invention will suitably consist essentially of from about 5% to about 95% by volume of water with a preferred range from about 20 to about 80% by volume of water, from about 5% to about 95% of oil with a preferred range from about 20 to 80 volume percent of oil, and an emulsifying agent of the type illustrated in an amount in the range from about 0.5 to about 20 grams per 100 ml. of the external phase of the emulsion. The weight percent of the inorganic weighting agent or salt dissolved in the aqueous or water phase will range from 1% up to about saturation, while the weight percent of organic compound or weighting agent dissolved in the oil phase will range from 1% up to about saturation. The film-strengthening agent of the type illustrated where required may range from about 0.1 to about 10 grams per 100 ml. of the aqueous phase of the emulsion. It is to be understood, of course, that when a weighting agent is used in the aqueous phase one ordinarily will not be required in the oil phase or vice versa although it is contemplated that, under some circumstances both phases may contain a weighting agent soluble in the respective phases.

The present invention will be further illustrated by reference to the drawing in which:

Figs. 1 to 4 illustrate a stepwise operation in accordance with the present invention.

Referring now to the drawing in which identical numerals will be employed to designate identical parts, numeral 11 designates a well bore drilled from the earth's surface, not shown, to penetrate a plurality of subsurface earth formations, sands, strata, zones, intervals, horizons, and the like which suitably may be designated by nu-

merals 12 13, and 14. Intervals 12 and 14 may be productive of hydrocarbons, such as oil and gas, while interval 13 may be non-productive. A casing 15 is arranged in the wellbore 11 and is cemented in place with primary cement 16. A tubing 17 is arranged in the casing 15 with its lower open end 18 arranged above the uppermost of the intervals 12, 13, and 14.

The casing 15 is shown filled with drilling mud indicated by the numeral 19.

In Fig. 2 a tubular extension member 20 is lowered through the tubing 17 by means of a wire line, not shown, and landed, supported, and suspended in a landing nipple 21 which may be a landing nipple of the type illustrated in the Composite Catalog of Oil Field and Pipeline Equipment, 19th edition, 1952-1953, page 4063. The tubular extension member 20 is suitably provided with a sealing means to seal between the upper end 22 of the tubular member 20 and the tubing 17.

In accordance with the present invention at least a portion of the drilling mud 19 is replaced by a body 23 of emulsion such as illustrated by pumping the emulsion 23 down the tubing 17 and out the tubular extension member 20 to provide a sandwich of emulsion 23 arranged between the displaced bodies of drilling mud 19, as shown in Fig. 2. After the emulsion 23 has been placed, as shown in Fig. 2, the tubular extension member 20 is retrieved from the tubing 17 by engaging a suitable wire line fishing tool, not shown, with the fishing neck 24 of the extension 20 and retrieving the tubular member 20 from the tubing 17. Thereafter a gun perforator, such as 25, which may be a tubing gun perforator or one of the shaped charge type or a punch type or chemical perforator or one which perforates casing by mechanical means is lowered through the tubing 17 by a wire line 26 and is inserted and/or located in the emulsion 23. The perforator 25 is then operated or fired to form a plurality of perforations 27 in the formation or interval 12. By

virtue of the emulsion 23 being free of solid materials and having the characteristics of low fluid loss and further the characteristic of displacing drilling mud, the perforations 27 are clean and hydrocarbons may be easily produced from the formation 12.

Thereafter, as illustrated in Fig. 4, the perforator 25 is withdrawn on wire line 26 and a second tubular member, such as 28, which is similar to tubular member 20 except of greater length, is lowered on wire line 26 engaged to fishing head 29 and landed and supported in landing nipple 21. Thereafter the drilling mud 19, both above and below the emulsion 23 may be circulated out of the well by flowing a washing liquid, such as water, indicated generally by the numeral 30, down the annulus between the tubing 17 and the casing 15. However, it is to be understood that the emulsion may be used as the washing liquid to remove the drilling mud by circulating the emulsion down the annulus between the tubing 17 and the casing 15. The washing liquid causes the mud and emulsion to be flowed up through the tubular extension member 28 and thence upwardly through the tubing 17. Production is then had from the clean perforations 27 into the casing 15. The tubular extension member 28 may be withdrawn and production continued through the open end 18 of the tubing 17.

In order to illustrate the present invention further, a number of compositions of emulsions in accordance with the present invention were made. In these operations, emulsions were prepared by mixing oily materials with water containing inorganic salts as weighting agents. Various amounts of the several emulsifying agents were added and the mixtures emulsified in a high speed agitator. The properties of the emulsion, such as density and API fluid loss, are also given.

The composition and properties of emulsion prepared with sodium chloride as a soluble weighting agent are presented in Table III:

TABLE III

The composition and properties of several emulsions prepared with sodium chloride as a soluble weighting agent

Sample Number	External Phase of the Emulsion	Aqueous Phase, Vol. Percent	Composition of Aqueous Phase			Oil Phase		Emulsifier		Properties of Emulsion	
			Film-Strengthening Agent		NaCl, Wt. Percent	Identity	Vol. Percent	Identity	grams/100 ml. External Phase	Density, lbs./gal.	API Fluid Loss, ml./30 min.
			Identity	grams/100 ml.							
1	oil	80	70-DH CMC	2.0	26	Diesel oil	20	Span 80	5.0	9.3	0.2
2	do	80	Filcon SPF	1.25	26	do	20	do	5.0	9.3	0.0
3	do	78	XHL Vis. CMC	1.0	26	do	22	do	2.50	9.2	4.2
4	do	75	Filcon SPF	1.67	26	do	25	do	5.0	9.1	0.8
5	do	75	Filcon SPF	5	26	do	25	do	4.0	9.3	0.5
6	do	75	XHL Vis. CMC	1.0	26	do	25	do	2.50	9.1	3.8
7	do	80	70-DH CMC	2.0	5	do	20	do	5.0	8.2	1.0
8	do	67	XHL Vis. CMC	1.0	none	do	33	do	1.67	7.75	1.4
9	do	80	70-H CMC	2.0	26	Diesel oil	10	Arlacel "C"	5.0	10.0	4.0
						CCl ₄	10				
						Diesel oil	12.5				
10	do	75	Filcon SPF	6.67	26	CCl ₄	12.5	do	10	10	1.0
11	do	75	do	5	26	Diesel oil	25	Span 80	4.0	9.3	4.5
12	water	80	none	0.0	26	do	20	Saltkem	5.0	9.3	2.4
13	do	80	do	0.0	26	do	20	do	6.25	9.3	0.0
14	do	72	do	0.0	26	do	28	do	7.95	9.1	2.2
15	do	80	do	0.0	26	do	20	do	5.0	9.3	2.4
16	do	55	do	0.0	26	do	45	do	4.0	8.5	6.2
17	do	50	do	0.0	26	do	50	do	4.0	8.3	8.4
18	do	40	do	0.0	26	do	60	do	5.0	8.33	5.8
19	do	35	do	0.0	26	do	65	do	6.95	7.85	5.8
20	do	33	do	0.0	5	do	67	do	16.7	7.75	2.0
21	do	30	do	0.0	5	do	70	do	10.0	7.65	4.6
22	do	83	do	0.0	26	CCl ₄	17	do	7.95	10.3	2.5
23	do	67	do	0.0	26	CCl ₄	33	do	3.18	11.6	4.2

It will be seen from the data presented in Table III that emulsions have been produced which have densities ranging from slightly over 7 pounds to over 11 pounds which have very low fluid losses. This is highly desirable in well perforating fluids.

Further additional emulsions were prepared in accordance with the foregoing procedure wherein calcium chloride was the soluble weight agent. The composition and properties of these emulsions are presented in Table IV:

From the data presented in Table IV, it will be noted that emulsions having densities ranging from above 7 to 10 pounds per gallon having low fluid losses were prepared.

Additional emulsions with potassium carbonate as the soluble weighting agent were prepared in accordance with the foregoing procedures. In this particular instance, emulsions with carbon tetrachloride as the oily phase

TABLE IV

The composition and properties of several emulsions prepared with calcium chloride as a soluble weighting agent

Sample Number	Ex-ternal Phase of the Emul-sion	Aqueous Phase, Vol. Per-cent	Composition of Aqueous Phase			Oil Phase		Emulsifier		Properties of Emulsion	
			Film-Strengthening Agent		CaCl ₂ , Vol. Percent	Identity	Vol. Per-cent	Identity	grams/100 ml. Ex-ternal Phase	Density, lbs./gal.	API Fluid Loss, cc./30 min.
			Identity	grams/100 ml.							
1	Oil	75	Filcon SPF	6.67	40	Diesel Oil	25	Span 80	10.0	10.0	8.0
2	do	75	do	6.67	40	do	25	Arlacel "C"	10.0	10.0	1.0
3	do	75	do	6.67	40	do	25	Atpet 100	10.0	10.0	1.0
4	do	75	do	6.67	25	do	25	Arlacel "C"	10.0	9.2	8.5
5	do	75	do	6.67	25	Diesel Oil	12.5	do	10.0	10.0	1.0
6	Water	75	none	0.0	3.0	CCl ₄	12.5	Saltkem	6.7	8.0	5.0
7	do	60	do	0.0	3.0	Diesel Oil	25	do	6.7	7.7	7.0
8	do	50	do	0.0	3.0	do	40	do	10.0	7.5	2.0
9	do	38	do	0.0	3.0	do	50	do	10.7	7.3	2.6
10	do	38	do	0.0	3.0	do	62	do	12.2	7.3	2.0
11	do	33	do	0.0	3.0	do	67	do	16.7	7.3	0.2

were prepared. The composition and properties of these emulsions are presented in Table V:

TABLE V

The composition and properties of several emulsions prepared with potassium carbonate as a soluble weighting agent

Sample Number	Ex-ternal Phase of the Emul-sion	Aqueous Phase, Vol. Per-cent	Composition of Aqueous Phase			Oil Phase		Emulsifier		Properties of Emulsion	
			Film-Strengthening Agent		K ₂ CO ₃ , Wt. Percent	Identity	Vol. Per-cent	Identity	grams/100 ml. Ex-ternal Phase	Density, lbs./gal.	API Fluid Loss, cc./30 min.
			Identity	grams/100 ml.							
1	oil	80	XHI Vis. CMC	1.0	43	CCl ₄	20	Arlacel "C"	2.5	12.4	1.0
2	do	80	do	1.0	47	CCl ₄	20	do	2.5	12.7	4.2
3	do	80	do	2.0	47	CCl ₄	20	do	2.5	12.7	4.8
4 ¹	do	80	do	2.0	47	CCl ₄	20	do	2.5	12.7	2.2
5	do	80	do	2.0	47	CCl ₄	20	G-2354	2.5	12.7	5.0
6	do	80	do	2.0	47	Diesel oil	20	do	2.5	11.3	2.4
7	do	80	do	1.0	47	do	20	do	2.5	11.3	3.6
8	do	80	do	1.0	47	do	20	do	2.5	11.3	1.8
9 ²	do	60	do	2.0	47	CCl ₄	40	Arlacel "C"	1.25	12.8	12.6
10 ²	do	60	do	2.0	47	CCl ₄	40	do	1.25	12.8	12.0
11	do	80	Filcon SPF	5.0	47	Diesel oil	20	do	2.5	11.3	3.0
12	do	75	do	6.67	43	do	25	Atpet 100	10	10	1.5
13	do	78	70-SH CMC	1.82	33	do	22	Span 80	2.0	10.0	0.6
14	do	80	Filcon SPF	5.0	47	CCl ₄	20	Arlacel "C"	2.5	12.7	10.0
15	do	75	XHI Vis. CMC	2.0	47	CCl ₄	25	do	5.0	12.8	3.0
16	do	75	do	1.0	47	CCl ₄	25	G-2354	5.0	12.8	3.4
17	do	75	Filcon SPF	5.0	47	CCl ₄	25	Span 80	10	12.8	4.8
18	do	78	70-SH CMC	1.71	47	CCl ₄	22	Atpet 100	10.0	12.7	1.0
19	do	75	do	2.0	47	CCl ₄	25	Arlacel "C"	5.0	12.8	1.8
20	do	80	XHI Vis. CMC	1.0	47	CCl ₄	20	G-1020	6.25	12.7	17
21	do	80	do	1.0	47	CCl ₄	20	Renex-30	6.25	12.7	17
22 ³	do	80	do	1.5	47	CCl ₄	20	Tween 60	6.25	12.7	34
23	do	55	do	1.5	47	CCl ₄	45	Span 20	7.25	12.8	4.4
24	do	80	do	1.5	47	CCl ₄	20	Tween 60	1.82	12.7	19
25	do	80	Filcon SPF	5.0	47	CCl ₄	20	Brij-30	6.25	12.7	34
26	do	80	XHI Vis. CMC	1.5	47	CCl ₄	20	do	6.25	12.7	34
27	do	80	Saltkem	6.67	47	CCl ₄	20	Renex-30	6.25	12.7	35
	do	80	Filcon SPF	5.0	47	CCl ₄	20	Tween 60	6.25	12.7	5.4

¹ Sample 4 homogenized.

² CMC not in solution.

³ Filcon not in solution; stable.

It will be noted from an examination of the data in Table V that the emulsions had low fluid losses and had densities ranging from 10 to nearly 13 pounds per gallon.

Additional emulsions were prepared with zinc chloride as the weighting agents. The composition and properties of these emulsions are presented in Table VI:

It will be clear from an examination of the data in Table VI that emulsions having densities ranging from about 11 to about 16 pounds per gallon may be prepared without employing solids.

In order to illustrate the stability of emulsions, selected emulsions were exposed to high temperatures in the range

TABLE VI

The composition and properties of several emulsions prepared with zinc chloride as a weighing agent

Sample Number	External Phase of the Emulsion	Aqueous Phase, Vol. Percent	Composition of Aqueous Phase			Oil Phase		Emulsifier		Properties of Emulsion	
			Film-Strengthening Agent		ZnCl ₂ , Wt. Percent	Identity	Vol. Percent	Identity	grams/100 ml. External Phase	Density, lbs./gal.	API Fluid Loss, ml./30 min.
			Identity	grams/100 ml.							
1.	oil	75	XHI, Vis. CMC	1.0	53	Diesel oil	25	Span 80	3.3	11.6	10.8
2.	do	75	do	1.0	53	CCl ₄	25	do	3.3	13.3	7.8
3.	do	75	do	1.5	53	CCl ₄	25	do	2.5	13.3	10.6
4.	do	75	do	1.5	53	CCl ₄	25	Arlacel C	2.5	13.3	9.0
5.	do	75	Filcon SPF	6.7	70	CCl ₄	25	do	10.0	15.6	1.0
6.	do	75	Guar flour	2.0	53	CCl ₄	25	do	2.5	13.3	12.0
7.	do	75	Driscose	5.0	53	CCl ₄	25	do	2.5	13.3	19.0
8.	water	80	none	0.0	70	CCl ₄	20	Saltkem	5.0	15.8	1.8
9.	oil	50	Saltkem	10.0	70	CCl ₄	50	Span 80	5.0	14.8	2.0
10.	water	80	none	0.0	60	Diesel oil	20	Saltkem	5.0	13.0	0.0
11.	do	80	do	0.0	47	CCl ₄	20	do	10	12.2	9
12.	do	75	do	0.0	70	CCl ₄	25	do	5.0	15.6	5.0
13.	do	65	do	0.0	60	Diesel oil	35	do	5.0	11.8	1.2
14.	do	67	do	0.0	47	do	33	do	10	11.2	3.9
15.	do	75	do	0.0	70	CCl ₄	25	do	6.7	15.6	2.5
16.	do	52	do	0.0	47	CCl ₄	48	do	6.15	12.9	8.4

from about 180° F. to 190° F. and the properties thereof determined after varying periods of exposure to the aforesaid temperatures. The composition and the filtration rate of the selected emulsions before and after exposure to the high temperatures are presented in Table VII:

TABLE VII

Filtration rate of selected emulsions before and after exposure to high temperature

Sample Number	External Phase of the Emulsion	Aqueous Phase, Vol. Percent	Composition of Aqueous Phase				Oil Phase		Emulsifier		Properties of Emulsion		
			Film-Strengthening Agent		Weighting Agent		Identity	Vol. Percent	Identity	grams/100 ml. External Phase	Density, lbs./gal.	API Fluid Loss, cc./30 min. ¹	API Fluid Loss, cc./30 min. ¹
			Identity	grams/100 ml.	Identity	Wt. Percent							
1.	Oil	80	Filcon SPF	1.25	NaCl	26	Diesel Oil	20	Span 80	5.0	9.3	0.0	1.0 (3 hr.)
2.	do	75	do	5.0	NaCl	26	do	25	do	5.0	9.3	0.5	0.5 (19 hr.)
3.	Water	80	none		NaCl		do	20	Saltkem	5.0	9.3	2.4	6.0 (19 hr.)
4.	Oil	75	Filcon SPF	6.67	CaCl ₂	40	do	25	Atpet 100	10.0	10.0	1.0	1.4 (24 hr.)
5.	do	75	70-SH CMC	2.0	K ₂ CO ₃	47	CCl ₄	25	Arlacel "C"	5.0	12.8	1.8	0.2 (48 hr.)
6.	do	75	Filcon SPF	6.67	ZnCl ₂	70	CCl ₄	25	do	10.0	15.6	1.0	9.0 (48 hr.)
7.	do	75	Saltkem	6.67	ZnCl ₂	70	CCl ₄	25	do	10.0	15.6	13.0	High (48 hr.)
8.	Water	75	none		ZnCl ₂	70	CCl ₄	25	Saltkem	6.7	15.6	5.0	9.0 (48 hr.)

¹ After exposure at 180-190° F. for the indicated number of hours.

Examination of the data in Table VII shows that the emulsions are quite stable and retain their property of low fluid loss even after extended periods of exposure to high temperature. This is important in well completion methods since temperatures in the range indicated may be encountered in wells.

In Table VIII the identity of the several film-strengthening agents employed is presented:

TABLE VIII

Information on film-strengthening agents used in preparation of emulsion

Trade Designation	Chemical Composition	Manufacturer
Filcon SPF	A sulfonated polymer ¹	Monsanto Chemical Company.
Driscose	Sodium carboxymethyl cellulose ²	Hercules Powder Company.
70-H CMO	do. ³	Do.
70-SH CMO	do. ⁴	Do.
70-DH CMO	do. ⁵	Do.
Guar Flour	Milled endosperm of guar seeds.	General Mills, Inc.
Saltkem	Sodium lignosulfonate	Marathon Corporation.
XH1. Vis. CMO	Sodium carboxymethyl cellulose ⁶	Dow Chemical Company.

¹ Filcon is a registered trade name of Monsanto Chemical Co., the manufacturer. The product disclosed in this application is a high molecular weight polymer of sulfonated phenol and formaldehyde (U. S. Patents 2,651,312 and 2,639,274).

² Average of 0.7 sodium carboxymethyl group per anhydroglucose unit, medium viscosity form, viscosity of 2% solution at 25° C.: 100-300 cp.

³ Average of 0.7 sodium carboxymethyl group per anhydroglucose unit, high viscosity form, viscosity of 1% solution at 25° C.: 1300-2200 cp.

⁴ Average of 0.7 sodium carboxymethyl group per anhydroglucose unit, special high viscosity form.

⁵ Average of 0.7 sodium carboxymethyl group per anhydroglucose unit, densified form of CMC-70 H, viscosity of 1% solution at 25° C.: 1300-2200 cp.

⁶ Average of about 0.3 to 0.4 sodium carboxymethyl group per anhydroglucose unit, extra high viscosity form.

Table IX is similar to Table VIII but gives the chemical composition of the emulsifying agents employed in the several examples:

TABLE IX

Information on emulsifiers used in preparation of emulsions

Trade Designation	Chemical Composition	Class of Agent	Manufacturer
Span 80	Sorbitan monooleate	non-ionic	Atlas Powder Company.
Arlacel "C"	Sorbitan sesquileate	do.	Do.
Atpet 100	Unpurified sorbitan monooleate	do.	Do.
Renex 30	Polyoxyethylene esters of mixed fatty and resin acids.	do.	Do.
Tween 60	Polyoxyethylene sorbitan monostearate	do.	Do.
Brij 30	Polyoxyethylene lauryl alcohol	do.	Do.
Saltkem	Sodium lignosulfonate	anionic	Marathon Corporation.
G-2854	Polyoxyethylene sorbitol tetraoleate	non-ionic	Atlas Powder Company.
Span 20	Sorbitan monolaurate	do.	Do.
G-1020	Polyoxyethylene sorbitol monolaurate	do.	Do.

In order to illustrate the invention further, several perforating targets were prepared by cementing 10" by 3½" Berea outcrop cores into 4½" casing. A ⅜" steel plate was provided at one end to simulate well perforating conditions. Emulsions were prepared in accordance with the present invention and placed in the perforating chamber and the targets and chambers were maintained at 180° F. for 24 hours. A pressure differential of 500 pounds per square inch was placed across the target with the pressure differential into the core and then the target was perforated by firing into the target. After allowing time for filtration, which varied from about 4 to about 24 hours, the target was backflowed to determine if any breakdown pressure was required. The final permeability of the perforated target to kerosene was obtained and compared to the target's initial permeability before perforating. In two of the cases the target perforations were acidized with 5% HCl. After acidizing, the final permeability of each treated target to kerosene was then obtained. The targets were then cut open and the perforation depth and clean-out noted. The results of these operations are presented in Table X.

The data in Table X show that the operations using emulsions as perforating fluid give quite satisfactory results. The first two emulsions had a very low fluid loss into the target. The third emulsion, which was an oil-in-water type as contrasted to a water-in-oil type of the first two, gave a higher fluid loss but the recovered permeability indicates little, if any, filtrate damage to the core. The results also show that acidizing the cores increases their permeability. In one case, the permeability after acidization was higher than the original permeability of the core. Observations on the perforated targets indicated that a very small pressure differential initiated flow.

The fact that only a small pressure differential was required to initiate flow through the perforations is considered very important. This means that in a well all perforations made in an emulsion perforating medium will open to flow. This is not the case where mud is used as a perforating medium.

It will be seen from the foregoing several examples that an improved perforating technique has been provided which allows clean perforations to be formed by perforating with a clean emulsion which is free of solids. Furthermore, it has been possible to provide emulsions which have the property of displacing the drilling fluid without being displaced by the drilling fluid. In other words, an emulsion which has an inorganic weighting agent is provided which is free of solids and is of sufficient weight and/or viscosity to displace the drilling mud.

The perforating fluid of the present invention, by virtue of being free of solids, is also of value for use in work-over operations besides perforation in wells. For example, the fluids may be used wherever there is danger of damaging a formation by contact with fluids which might plug or reduce the permeability or porosity of the

TABLE X

Data on targets perforated in emulsion perforating fluid

Test No.	Perforating Fluid Composition					Emulsion Properties			Target Permeabilities		
	Oil Phase, Percent by vol.	Water Phase, Percent by vol.	Film-Strengthening Agent	Emulsifier	Weighting Agent, Percent by vol.	Weight, lbs./gal.	Fluid Loss, API	Fluid Loss into Target	Before Perforating, millidarcies	After Perforating, millidarcies	After Acidizing, millidarcies
335	25 (D. O.)	75	5% Filcon in H ₂ O	1% Span 80 in oil	26% NaCl	9.3	4.5	15.8 cc./4.2 hrs.	190	125 (after 4 hrs.)	
336	25 (D. O.)	75	do.	do.	do.	9.3	0.5	16.9 cc./24 hrs.	215	154 (after 7 days)	200
337	20 (D. O.)	80	None	5% Saltkem in H ₂ O	do.	9.3	2.4	66.7/4.5 hrs.	240	187 (after 7 days)	316

formation. Washing and circulating operations are exemplary of uses where the emulsion perforating fluids may be employed.

The present invention is, therefore, of considerable utility and advantage in perforating wells.

The nature and objects of the present invention having been completely described and illustrated, what we wish to claim as new and useful and to secure by Letters Patent is:

1. A method for completing a well penetrating a sub-surface earth formation while maintaining said well under control with a fluid column having a hydrostatic pressure in excess of formation pressure which comprises replacing only a portion of the drilling fluid in a casing in said well with a solids-free heat stable emulsion which consists of from about 5% to about 95% by volume of an aqueous medium, from about 5% to about 95% by volume of an oily medium, a weighting agent in an amount within the range between 1% to about saturation soluble and dissolved in at least one of said media, said weighting agent having a specific gravity greater than the specific gravity of the aqueous medium, and an emulsifying agent selected from the group consisting of sorbitan mono-oleate, sorbitan sesqui-oleate, polyoxyethylene sorbitan mono-stearate, polyoxyethylene lauryl alcohol, sodium lignosulfonate, polyoxyethylene sorbitol tetraoleate, polyoxyethylene sorbitol monolaurate, unpurified sorbitan mono-oleate, sorbitan monolaurate, and polyoxyethylene esters of mixed fatty and resin acids in an amount within the range between 0.2 and about 20 grams per ml. of the external phase of the emulsion, inserting a perforator in the emulsion, and operating the perforator in the emulsion to form clean perforations in said casing, said emulsion having a weight in the range from about 7 to about 18 pounds per gallon, being heat stable, and having a low fluid loss at high well temperatures whereby said earth formation is protected from damage by contact with fluids which might plug or reduce the permeability or porosity of the formation.

2. A method in accordance with claim 1 in which the soluble weighting agent is dissolved in the aqueous medium.

3. A method in accordance with claim 1 in which the soluble weighting agent is dissolved in the oily medium.

4. A method in accordance with claim 1 in which the soluble weighting agent is an inorganic metal salt dissolved in the aqueous medium.

5. A method in accordance with claim 1 in which an organic weighting agent having a specific gravity in the range from about 1.2 to about 4 is dissolved in the oily medium.

6. A method in accordance with claim 1 in which the emulsion contains a film-strengthening agent in the range

from about 0.1 to about 10 grams per 100 ml. of the aqueous phase of the emulsion.

7. A heat stable well completion composition having a weight in the range from about 7 to about 18 pounds per gallon which consists of a solids-free emulsion containing from about 5% to about 95% by volume of an aqueous medium, from about 5% to about 95% by volume of an oily medium, a weighting agent having a specific gravity greater than the specific gravity of the aqueous medium in an amount within the range between 1% by weight to about saturation dissolved in at least one of said media, and an emulsifying agent selected from the group consisting of sorbitan mono-oleate, sorbitan sesqui-oleate, polyoxyethylene sorbitan mono-stearate, polyoxyethylene lauryl alcohol, sodium lignosulfonate, polyoxyethylene sorbitol tetraoleate, polyoxyethylene sorbitol monolaurate, unpurified sorbitan mono-oleate, sorbitan monolaurate, and polyoxyethylene esters of mixed fatty and resin acids in an amount in the range between 0.2 and about 20 grams per 100 ml. of the external phase of the emulsion, said composition being heat stable and having a low fluid loss at high well temperatures.

8. A composition in accordance with claim 7 in which the emulsion contains a film-strengthening agent in an amount in the range from about 0.1 to about 10 grams per 100 ml. of the aqueous medium of the emulsion.

9. A composition in accordance with claim 7 in which the weighting agent is dissolved in the aqueous medium.

10. A composition in accordance with claim 7 in which the weighting agent is dissolved in the oily medium.

11. A composition in accordance with claim 7 in which the oily medium contains carbon tetrachloride.

12. A composition in accordance with claim 7 in which sodium chloride is the weighting agent dissolved in the aqueous phase.

13. A composition in accordance with claim 7 in which calcium chloride is the weighting agent dissolved in the aqueous phase.

14. A composition in accordance with claim 7 in which potassium carbonate is the weighting agent dissolved in the aqueous phase.

15. A composition in accordance with claim 7 in which zinc chloride is the weighting agent dissolved in the aqueous phase.

References Cited in the file of this patent

UNITED STATES PATENTS

2,430,039	Anderson	Nov. 4, 1947
2,693,856	Allen	Nov. 9, 1954
2,745,495	Taylor	May 15, 1956
2,748,079	Weiss	May 29, 1956
2,766,828	Rachford	Oct. 16, 1956