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中华人民共和国石油天然气行业标准

SY/T 5873—2005
代替 SY/T 5873.1—1993，SY/T 5873.2—1994，SY/T 5873.3—1993，
SY/T 5873.4—1993，SY/T 5903—1993，SY/T 5905—1993

中文/English

有杆泵抽油系统设计、施工推荐作法

Recommended practice for design and execution of sucker rod pumping system

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国家发展和改革委员会　　发　布

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前言

本标准整合修订并代替SY/T 5873.1—1993《有杆泵抽油作业工艺作法　常规抽油》、SY/T 5873.2—1994《有杆泵抽油作业工艺作法　小泵深抽》、SY/T 5873.3—1993《有杆泵抽油作业工艺作法　斜井抽油》、SY/T 5873.4—1993《有杆泵抽油作业工艺作法　大泵抽油》、SY/T 5903—1993《抽油杆柱组合设计方法》、SY/T 5905—1993《游梁式抽油机选型作法》。本标准与原六项标准主要差异如下：

——本标准的结构、标准要素及表述规则按GB/T 1.1—2000《标准化工作导则　第1部分：标准的结构和编写规则》的规定进行了修订。

——游梁式抽油机基本参数表，按SY/T 5044—2003《游梁式抽油机》规定修改；抽油机规格代号由原来的27种变为28种，其中增加了18-6-146型抽油机，相应的游梁式抽油机选型图也增加了该种机型。

——增加了抽油机安装内容。

——增加了斜井抽油杆柱组合设计方法，组合抽动杆柱代号组成修改为最上部抽油杆柱代号放在前面。

——抽油杆抗拉强度按SY/T 5029—2003《抽油杆》规定修改。

——增加了井下作业健康和安全环保的内容。

——管柱图按SY/T 5952《油气水井井下工艺管柱工具图例》的要求重新绘制。

——施工中一些内容直接引用现有标准。

——附录A、附录B、附录C、附录D、附录E均为资料性附录。

本标准由采油采气专业标准化委员会提出并归口。

本标准起草单位：中国石化胜利油田有限公司采油工艺研究院、大庆油田有限责任公司开发部。

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本标准所代替的历次版本发布情况为：

——SY/T 5873.1—1993；

——SY/T 5873.2—1994；

——SY/T 5873.3—1993；

——SY/T 5873.4—1993；

——SY/T 5903—1993；

——SY/T 5905—1993。

本标准以中文和英文两种文字出版。当英文与中文两种版本有歧义时，以中文版本为准。

有杆泵抽油系统设计、施工推荐作法

1 范围

本标准规定了游梁式抽油机选型及安装、抽油泵选择作法、抽油杆选择作法及抽油杆柱组合设计方法、生产管柱结构设计、施工等。

本标准适用于油田有杆泵抽油系统的设计、施工。

2 规范性引用文件

下列文件中的条款通过本标准的引用而成为本标准的条款。凡是注日期的引用文件，其随后所有的修改单（不包括勘误的内容）或修订版均不适用于本标准，然而，鼓励根据本标准达成协议的各方研究是否可使用这些文件的最新版本。凡是不注日期的引用文件，其最新版本适用于本标准。

GB/T 18607—2001 抽油泵及其组件规范
SY/T 0408—2000 抽油机安装工程施工及验收规范
SY/T 5029—2003 抽油杆
SY/T 5044—2003 游梁式抽油机
SY/T 5059 组合泵筒管式抽油泵
SY/T 5587.3—2004 常规修井作业规程 第3部分：油气井压井、替喷、诱喷
SY/T 5587.5—2004 常规修井作业规程 第5部分：井下作业井筒准备
SY/T 6361—1998 采油采气注水矿场健康、安全与环境管理体系指南
SY/T 6362—1998 石油天然气井下作业健康、安全与环境管理体系指南

3 代号

3.1 组合抽油杆柱代号采用杆柱最上部和最下部的抽油杆规格代号（见表1）组成，最上部抽油杆柱规格代号放在前面。例如，19 mm，16 mm，13 mm抽油杆组成的杆柱，则组合抽油杆柱代号表示为64。

表1 组合抽油杆柱代号

抽油杆规格代号	9	8	7	6	5	4
抽油杆直径 mm	29	25	22	19	16	13

3.2 物理量代号见表2。

表2 物理量代号

序号	量的符号	量的名称	单位符号
1	$[\Delta\sigma]$	许用应力范围	MPa
2	$[M_{\max}]$	额定扭矩	N·m
3	$[P_{\max}]$	额定悬点载荷	N
4	$\sum\alpha$	井段ΔL长度两端井斜角之和	(°)

表 2（续）

序号	量的符号	量 的 名 称	单位符号
5	Δi	第 i 级抽油杆柱所占百分比	1
6	ΔL	下泵深度处的井段长度	m
7	ΔL_i	i 井段内抽油杆长度	m
8	$\Delta\alpha$	井段 ΔL 长度两端井斜角之差	(°)
9	$\Delta\phi_{\mathrm{H}}$	井段 ΔL 长度两端方位角之差	(°)
10	a	常数，a =0.25	1
11	A_{o}	排出阀座孔截面面积	m^2
12	A_{p}	抽油泵柱塞截面面积	m^2
13	A_{r}	抽油杆柱按长度加权平均截面面积	m^2
14	$A_{\mathrm{r}i}$	第 i 级抽油杆柱横截面面积	m^2
15	A_{rJ}	校核点处抽油杆横截面面积	m^2
16	A_{r1}	最下部一级抽油杆横截面面积	m^2
17	A_{sJ}	校核点以下抽油杆柱按长度加权平均截面面积	m^2
18	A_{t}	油管柱按长度加权平均横截面面积	m^2
19	$A_{\mathrm{t}j}$	第 j 级油管柱金属部分横截面面积	m^2
20	A_{w}	加重杆横截面面积	m^2
21	b	常数，b=0.5625	1
22	C	下冲程动载荷修正系数，与抽油机的几何参数和泵的充满程度有关，在抽汲不含气液体时，一般取 C=0.85～0.9	1
23	D	油层套管内径	mm
24	d_{o}	排出阀孔座直径	m
25	D_{b}	抽油泵外径	mm
26	d_{p}	抽油泵公称直径	m
27	D_{p}	下泵深度	m
28	D'_{p}	斜井段下泵深度	m
29	D_{pf}	动液面深度	m
30	D_{ps}	抽油泵沉没度	m
31	$d_{\mathrm{r}i}$	i 井段抽油杆直径	m
32	D_{ti}	油管内径	m
33	E	钢的弹性模量	Pa
34	E'	加重杆系数	cm^3
35	f	抽油杆与油管之间的摩擦系数，视各油田原油性质不同而不同	1
36	F_2	泵筒与柱塞间摩擦载荷	N
37	F_{3i}	i 井段杆柱与液柱的摩擦力	N
38	F_{4i}	i 井段液柱与油管的摩擦力	N

表 2（续）

序号	量的符号	量的名称	单位符号
39	F_5	液体通过排出阀的水力阻力产生的对柱塞底部向上的推力	N
40	F_{i-1}	i 井段的抽油杆下端 $i-1$ 点的负荷	N
41	F_s	锚爪受压面面积	cm^2
42	F_t	油管横截面面积	m^2
43	f_w	井液含水率	1
44	g	重力加速度	m/s^2
45	H	油层中部深度	m
46	h	阀球与阀座接触点距阀罩内壁的距离	m
47	h_j	机械锚（或封隔器）的防坐距	cm
48	h_n	中和点以下油管或杆上任一点螺距	cm
49	i	抽油杆柱自下而上依次编排的级数，$i=1, 2, \cdots, M$	1
50	I	油管或杆横截面面积对其直径的惯性矩	cm^4
51	j	油管柱自下而上依次按管径编排的级数，$j=1, 2, \cdots, Z$	1
52	J	校核点以下的最上部一级抽油杆柱称为第 J 级	1
53	k	失重系数	1
54	K_{sf}	考虑腐蚀等因素所用的余量系数	1
55	K_{tr}	油管内径与抽油杆直径比	1
56	l	抽油杆柱级数，$l=1, 2, \cdots, l-1$	1
57	L	机械锚（或封隔器）以上油管长度	m
58	L_2	中和点以下至机械锚的油管长度	m
59	L_b	抽油泵的长度	mm
60	L_i	i 井段抽油杆柱长度	m
61	L_{i-1}	$i-1$ 井段抽油杆柱长度	m
62	L_j	第 j 级油管柱长度	m
63	L_J	校核点以下抽油杆柱长度	m
64	L_{max}	抽油杆柱的极限下泵深度	m
65	L_{ri}	组合杆柱中第 i 级抽油杆柱长度	m
66	L_{sb}	需配加重杆总长度	m
67	m_a	动载系数	m/s^2
68	$M_{ca,max}$	曲柄轴上承受的最大扭矩	N·m
69	n	冲次	min^{-1}
70	N_f	杆柱上安装的尼龙扶正器的个数	个
71	N_i	i 井段对应的抽油杆的单位长度对油管内壁的挤压力	N/m
72	n_e	锚爪数量	个
73	n_k	排出阀数目	个

表 2（续）

序号	量的符号	量 的 名 称	单位符号
74	N_{max}	最高冲次	min^{-1}
75	$P_{\mathrm{mh,max}}$	悬点最大载荷	N
76	$P_{\mathrm{mh,min}}$	悬点最小载荷	N
77	P_{1i}	i 井段对应抽油杆与油管之间的摩擦负荷	N
78	p_{b}	饱和压力	Pa
79	P_{br}	作用在抽油杆柱底部的液体上浮力	N
80	P_{Jmax}	校核点处抽油杆所承受的最大载荷	N
81	P_{Jmin}	校核点处抽油杆所承受的最小载荷	N
82	P_{L}	作用在抽油泵柱塞上的液体载荷	N
83	p_{n}	中和点以下油管或杆上任一点的压缩力	kN
84	p_{o}	井口回压	Pa
85	P_{ps}	要求泵充满程度为 β 时所需要的沉没压力	Pa
86	p_{s}	抽油泵泵吸入口压力	Pa
87	p_{sc}	标准状况下的压力，取 101×10^3	Pa
88	P_{t}	锚爪卡住套管时弹簧的反弹力	kN
89	P_{w}	下行程时抽油杆柱底部受的总下行阻力	N
90	p_{wf}	油层中部流压	Pa
91	Q	泵的排量	m^3/d
92	q_i	第 i 级抽油杆单位长度的重力	N/m
93	q_{L}	产液量	m^3/d
94	Q_{max}	泵的最大排量	m^3/d
95	q_{r}	抽油杆柱平均每米长度在空气中的重力	N/m
96	q_{s}	每米油管在井液中的重力	kN/m
97	R_{b}	阀球半径	m
98	Re	雷诺数	1
99	R_{go}	生产气油比	1
100	R_i	i 井段井眼轴线在垂直面上的投影的曲率半径	m
101	r_i	i 井段井眼轴线在水平面上的投影的曲率半径	m
102	R_{w}	井筒轴线曲率半径	m
103	R_{we}	抽油泵不弯曲时井筒轴线曲率半径	m
104	S	冲程	m
105	SF	古德曼使用系数。它是个经验数值，与油井腐蚀条件、抽油杆的维护操作因素有关，一般取 $SF=0.7\sim0.9$，使用新抽油杆和在无腐蚀的油井中工作时，SF 可取 1.0	1
106	S_{max}	悬点最大冲程	m

表 2（续）

序号	量的符号	量 的 名 称	单位符号
107	S_{pmax}	泵柱塞的有效最大冲程	m
108	T	抽油杆抗拉强度	Pa
109	t	泵挂处井温	℃
110	v	应力波在抽油杆柱中的传播速度，$v=4968$	m/s
111	W_j	每米加重杆在空气中的重力	N/m
112	W_{L}	液柱载荷	N
113	W_{ra}	抽油杆柱在空气中的重力	N
114	W_{rf}	抽油杆柱在液体中的重力	N
115	W_{rfJ}	校核点以下抽油杆柱在液体中的重力	N
116	$W_{\mathrm{r}i}$	i 井段的抽油杆每米重力	N/m
117	α	井斜角	(°)
118	α_{e}	保证抽油泵在所处井段稳定工作所允许的井斜角	(°)
119	α_i	i 井段上端的井斜角	(°)
120	α_{i-1}	i 井段下端的井斜角	(°)
121	α_{v}	加重杆对应井段平均井斜角	(°)
122	$\alpha_{\mathrm{v}i}$	i 井段两端井斜角的平均值	(°)
123	β	井段 ΔL 长度内的全角变化值	(°)
124	γ_{L}	液体重度	kN/m^3
125	γ_{t}	油井液的相对密度	1
126	δ	泵筒与柱塞在半径方向上的间隙	m
127	η	要求的泵充满程度	1
128	η_{p}	泵效	1
129	λ	抽油机从上冲程开始到全部液柱载荷加载给悬点时的悬点位移	m
130	λ_i	由惯性载荷影响造成柱塞冲程长度的增加值	m
131	λ_{J}	抽油机从上冲程开始到全部液柱载荷加载给校核点时的校核点的位移	m
132	μ	流量系数	1
133	μ_{o}	抽汲液体动力粘度	mPa·s
134	ξ	浮力系数，$\xi=0.872$	1
135	ρ_{r}	钢的密度	kg/m^3
136	ρ_{wL}	液体密度	kg/m^3
137	$\sigma_{\mathrm{r,max}}$	最大应力	MPa
138	$\sigma_{\mathrm{r,min}}$	最小应力	MPa
139	$\sigma_{\mathrm{rp,max}}$	抽油杆许用最大应力	MPa
140	ϕ_{c}	抽油机从上冲程开始到全部液柱载荷加载给悬点时的曲柄转角	rad
141	ϕ_{cJ}	抽油机从上冲程开始到全部液柱载荷加载给校核点时的曲柄转角	rad

表 2（续）

序号	量的符号	量 的 名 称	单位符号
142	$\phi_{\mathrm{H}i}$	i 井段井眼轴线下端方位角	(°)
143	$\phi_{\mathrm{H}i-1}$	i 井段井眼轴线上端方位角	(°)
144	ψ	变形分布系数	1
145	ψ_1	校核点以下抽油杆柱与油管柱决定的变形分布系数	1

4　游梁式抽油机选型及安装

4.1　游梁式抽油机选型原则

4.1.1　在一定参数配合和需要的下泵深度下，抽油机的选择主要由悬点载荷和曲柄扭矩两项指标来确定，即悬点最大载荷 $P_{\mathrm{mh,max}}$ 及曲柄轴最大扭矩 $M_{\mathrm{ca,max}}$ 不超过它们额定值［见式（1）、式（2）］：

$$P_{\mathrm{mh,max}} \leqslant [P_{\max}] \quad \cdots\cdots (1)$$

$$M_{\mathrm{ca,max}} \leqslant [M_{\max}] \quad \cdots\cdots (2)$$

4.1.2　所选择的游梁式抽油机，应满足油田开发方案长期需要。

4.1.3　所选择的游梁式抽油机，应在使用期的大部分时间内具有较高的载荷利用率、扭矩利用率和电机功率利用率。

4.1.4　尽可能选用节能抽油机。

4.1.5　所选择的抽油机应进行区域统筹，对同一油区或同一个采油厂或油田，所选机型不宜太杂，流体性质和载荷要求都相近的井尽量选择同一规格和型号的抽油机。

4.2　游梁式抽油机选型图绘制

4.2.1　根据 4.1 规定的选型原则，并考虑抽油机选型和整个抽油系统设计的协调通用性，加入了抽油杆柱应力强度的限定条件，经公式变换计算后，绘得游梁式抽油机选型图，参见图 A.2～图 A.5。游梁式抽油机选型图绘制依据参见附录 A。

4.2.2　图 A.2～图 A.5 中，Ⅰ区用在泵排量 200 $\mathrm{m^3/d}$ 以下，Ⅱ区用在泵排量 200 $\mathrm{m^3/d}$～400 $\mathrm{m^3/d}$ 范围，Ⅲ区用在泵排量 400 $\mathrm{m^3/d}$ 以上条件。

4.3　游梁式抽油机选型方法

4.3.1　根据油井具体情况和现有抽油机机型种类以及 4.1 规定的原则，按照不同冲程选择确定要用的选型图。

4.3.2　根据设定的油井产液量 q_{L} 和所需相应的下泵深度 D_{p}，在选定的选型图上从横坐标轴上找出和 D_{p} 值相应的点，由此点作横坐标轴垂线；在纵坐标轴上找出和油井产液量 q_{L} 值相应的点，并由此点作纵坐标轴的垂线，上述两条垂线的交点所在区域的抽油机规格代号即可选为此条件下的最佳抽油机规格代号。

4.3.3　根据设定的抽油机适用年限，预测其油井末期生产动态，并重新考虑 4.3.1 和 4.3.2 步骤。这样选择的机型就可满足油井生产变化的年限要求。

4.3.4　在无法预测抽油机适用年限末期油井动态时，为满足抽油机的适用年限性，一般在 4.3.2 步骤的基础上，应选大 1 个等级的机型为最终选择的机型。

4.3.5　游梁式抽油机选型示例参见附录 A 中 A.5。

4.4　游梁式抽油机安装

抽油机的现场安装与抽油机出厂前的总装顺序基本相同。油井现场组装时，底座安装位置有较严格的尺寸限制，以保证旋绳器对中井口。抽油机安装时请参阅随机说明书，并执行 SY/T 0408—2000 中有关抽油机安装的要求。

5 抽油泵选择作法

5.1 抽油泵选择原则

5.1.1 所选择的泵径，应以当前油井的预测产能为计算依据。对流体性质和下泵深度为常规条件的井，应以最大冲程、中等冲次为原则计算得出；对稠油或深泵挂井，应以最大冲程、较低冲次计算得出，以求得合理的生产效果，而且能在投产后，当油井的实际供液能力与预测值有一定出入时有地面调整参数的余地。

5.1.2 选择的泵间隙等级，应根据井液的粘度确定，一般条件（<0.1 Pa・s）可选用Ⅰ级泵，井液粘度较高（0.1 Pa・s～0.43 Pa・s）可选用Ⅱ级泵，对高粘度油井（0.43 Pa・s ～1.10 Pa・s）可选用Ⅲ级泵，各级泵的最大漏失量应不高于SY/T 5059中规定的数值。

5.1.3 对产量小的深抽井，应优先选用杆式泵。

5.1.4 对含气高、多砂、高粘等特殊条件的油井，可考虑采用特殊泵型，如防气泵、防砂泵、抽稠泵等；对因某些原因需下长尾管的油井，应采用过桥泵；对长冲程抽油井，可采用整筒泵；对高产能而套管直径相对较小的油井，可使用串联泵；对于斜井，应优先选择整筒悬挂式泵。

5.2 抽油泵泵效的选取

5.2.1 根据同层系的油井选取泵效值。

5.2.2 根据施工前一段时期的生产综合记录选取泵效值。

5.2.3 一般推荐泵效值为60%～70%。

5.3 抽油泵泵径确定

泵径按式（3）计算：

$$d_p = 0.0297\sqrt{\frac{q_L}{Sn\eta_p\rho_{wL}}} \quad \cdots\cdots (3)$$

5.4 抽油泵下泵深度确定

5.4.1 直井按式（4）计算：

$$D_p = H - \frac{p_{wf} - p_{ps}}{\rho_{wL}g} \quad \cdots\cdots (4)$$

其中：

$$p_{ps} = \frac{R_{go}p_{sc}p_b\ (1-f_w)\ (273+t)\ /293}{p_b\ (1/\beta-1)\ +R_{go}p_{sc}\ (1-f_w)\ (273+t)\ /293}$$

5.4.2 斜井：首先确定斜井下泵垂直深度（D_p），并折算出下泵的斜长深度（D'_p）。调整下泵垂直深度，使其符合井斜角和井眼曲率半径的限制。

5.4.2.1 折算的下泵斜长深度处井段井斜角 $\alpha \leqslant 35°$ 时，该下泵深度可初步确定。

5.4.2.2 当井斜角 $\alpha > 35°$ 时，必须用保证抽油泵稳定工作允许的井斜角（α_e）进行验证，按式（5）计算：

$$\alpha_e = 2\ \left(\arccos\sqrt{\frac{h}{2R_b}} - 45\right) \quad \cdots\cdots (5)$$

5.4.2.3 下泵深度处井段 ΔL 长度内井筒轴线曲率半径 R_w 必须大于抽油泵不产生弯曲的井筒轴线曲率半径 R_{we}，即 $R_w > R_{we}$。

保证抽油泵不产生弯曲的井筒轴线曲率半径（R_{we}）按式（6）计算：

$$R_{we} = \frac{L_b^2}{8\ (D-D_b)} \quad \cdots\cdots (6)$$

下泵深度（D_p）处井段 ΔL 长度内井筒轴线的曲率半径（R_w）按式（7）计算：

$$R_w = \frac{\Delta L\ \sqrt{2\ (1+\cos\beta)}}{2\sin\beta} \quad \cdots\cdots (7)$$

其中：

$$\beta=\sqrt{\Delta\alpha^2+\Delta\phi_{\mathrm{H}}^2\sin^2\frac{\sum\alpha}{2}}$$

当井斜角不大于12°时，要求$R_w>R_{we}$；而当井斜角大于12°时，除要求$R_w>R_{we}$外，还要求ΔL井段的井斜全角变化律小于0.125°/25 m，且该井段的长度大于50 m。

5.4.2.4 泵挂井段以上的其他井段井斜全角变化率应小于10°/25 m。

5.4.2.5 确定的下泵深度，在动液面、含水等有变化的情况下，能够保证有稳定的油井产量。

6 抽油杆选择作法及抽油杆柱组合设计方法

6.1 抽油杆选择原则

6.1.1 抽油杆材质和级别的选择，应根据油井流体性质和载荷类型确定，抽油杆等级和对应的抗拉强度见表3。

表3 抽油杆的力学性能

抽油杆等级	K	C	D	H
抽油杆抗拉强度 MPa	620～793	620～793	793～965	966～1136

6.1.2 在轻载荷或中载荷有轻微盐水腐蚀的油井中，选择C级抽油杆。

6.1.3 在中载荷有腐蚀介质CO_2，H_2S及含砂、含蜡高的油井中，选择K级抽油杆。

6.1.4 在重载荷有轻微盐水腐蚀的油井中，选择D级或H级抽油杆。

6.2 抽油杆柱组合设计方法

6.2.1 抽油杆柱近似等强度组合设计方法

抽油杆柱设计采用修正的古德曼应力图，采用多级杆柱组合为最佳。杆柱级数、各级杆长按照各级杆等强度原则，并考虑到保持质量最小，通过计算确定，也可以从附录B中表B.1上直接查找，设计时各级杆的最大应力差应在0.5 MPa。同时，为了减少70 mm以上泵或深抽时抽油杆下部的断裂次数，对抽油杆下部可以考虑加重，防止杆柱的纵向弯曲。

6.2.1.1 抽油杆柱下部加重杆设计

设计方法与步骤参见附录C中C.1.1～C.1.6。

6.2.1.2 加重杆上部抽油杆柱组合设计

设计方法与步骤参见附录C中C.2。

6.2.2 抽油杆柱等强度组合设计方法

6.2.2.1 抽油杆柱下部加重杆设计

直井设计方法与步骤参见附录C中C.1.1～C.1.6，斜井设计方法与步骤参见附录C中C.1.1～C.1.7。

6.2.2.2 加重杆上部抽油杆柱组合设计

直井设计方法与步骤参见附录C中C.3，斜井设计方法与步骤参见附录C中C.4。

6.2.3 抽油杆柱组合设计示例

抽油杆柱组合设计示例参见附录C中C.5。

7 生产管柱结构设计

7.1 抽油杆柱结构

7.1.1 抽油杆柱的基本结构自上而下的组成顺序是光杆、抽油杆（单级或多级）、柱塞（见图1）。

7.1.2 因油井条件或管柱结构的需要在杆柱上安装相关的井下工具（见图2）。

7.1.2.1 在油管内径小于泵柱塞直径时，需要在杆和柱塞之间连接脱接器。

7.1.2.2 对使用泄油器的井，可根据泄油器结构型式的需要在杆柱上相应位置加装控制块（或开泄器）。

7.1.2.3 在杆柱中和点以下及方位角变化较大的井段可加装防脱器。

7.1.2.4 在可能或已经发生过偏磨区段或中和点以下，应安装相应的抽油杆扶正器。

抽油杆扶正器一般在中和点以下安装，原则上是由下向上逐步加大间距，其螺旋弯曲的螺距按式（8）计算：

$$P_n=[3.3\ (d_p^2-d_o^2)\cdot(d_p/d_o)^4\cdot(Sn/\mu)^2\gamma_L\times10^{-4}+1770d_p-14]\times10^{-2} \quad \cdots\cdots(8)$$

对于斜井，扶正器的配置应满足式（9）的限制条件：

$$W_{rf}/N_f>50 \quad \cdots\cdots(9)$$

对于井斜全角变化率小于7°/30m井段，应用单根杆安装3个扶正器即可；对于井斜全角变化率大于7°/30 m或易结蜡井段，可以考虑适当加密扶正器的数量，一般应不少于4个。

7.1.2.5 对易结蜡油井，可在杆柱上适当位置加装防蜡器，或在易结蜡区段加装抽油杆刮蜡器。

7.1.2.6 为减少悬点最大载荷和交变载荷，可在杆柱适当位置加装缓冲器。

7.2 油管柱结构

7.2.1 基本油管柱结构

基本油管柱结构，自上而下的组成顺序是油管、泵、筛管、尾管和死堵（见图3）。

7.2.2 常规油管柱结构

因油井条件需要加装各种井下工具的常规油管柱结构见图4。

7.2.2.1 对使用脱接器的井，需在泵上加装脱接工作筒（或称为油管短节和脱接环）。

7.2.2.2 对无自喷能力的井，应在管柱下部加装泄油器。

7.2.2.3 对泵挂较深的井，可根据管柱情况对油管进行锚定。

7.2.2.4 为避免油管摆动和油管螺旋弯曲，可在油管下半部加装油管扶正器。对泵挂较深的井，也要考虑加装油管扶正器。油管扶正器的安装数量视泵挂深度及管柱情况而定，其安装位置按式（10）计算：

$$h_n=\pi\sqrt{8\times10^{-6}EI/P_n} \quad \cdots\cdots(10)$$

7.2.2.5 对易结蜡油井，应在泵和筛管之间或管柱上适当位置加装防蜡器。

7.2.2.6 对气液比大而需要采取防气措施的井，可用气锚取代筛管。

7.2.2.7 对需要采取防砂措施的井，可用防砂筛管代替常规筛管。

7.2.3 分采油管柱结构

7.2.3.1 丢手分采管柱

已明确长期堵水层位的井或下泵深度与堵水层位距离较大的井，同时该井不属于套管变形区，则应使用丢手分采管柱（见图5）。丢手分采管柱上所用封隔器的个数和型号，可根据分采层位情况及管柱是否支撑井底等确定。

7.2.3.2 整体分采管柱

7.2.3.2.1 封上层采下层和封中间层采上下层井的分采管柱见图6。

7.2.3.2.2 封下层采上层井的分采管柱见图7。

7.2.3.2.3 封上下层采中间层井的分采管柱见图8。

7.2.4 丢手不压井管柱

常规抽油管柱尾部接扶正器和捅杆。丢手封隔器定位于套管射孔顶界以上，丢手封隔器下接活门，活门下接筛管、尾管和死堵，抽油管柱上部加装井口工作筒见图9。

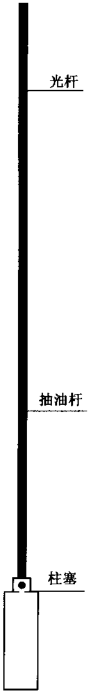


图 1

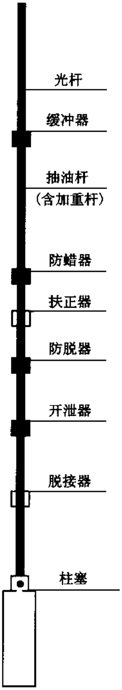


图 2

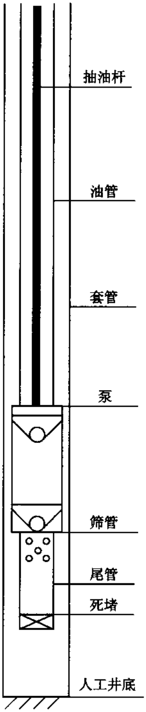


图 3

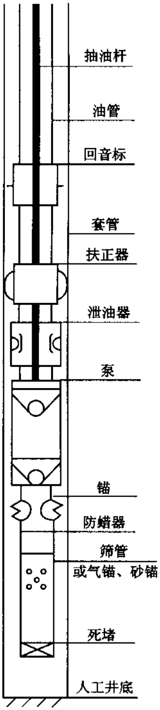


图 4

7.2.5 偏心测试管柱结构

对 140mm 套管，使用 56mm 及以下泵径时，在偏心井口条件下，把常规抽油管柱的尾端死堵改用导锥形死堵（见图 10）。

7.2.6 热洗防压井管柱

对油层压力低的非大套管井，在常规抽油管柱以下接一级封隔器坐封在射孔顶界以上，封隔器以下接单流阀（见图 11）。

7.3 油管柱选配要求

7.3.1 除地层压力明显低于静液柱压力、井口无法装不压井控制器及只有压井才能进行起下作业的特殊工艺外，管柱的设计宜采用不压井工艺。

7.3.2 对装有偏心井口的井，管柱尾端应采用锥形死堵，管柱尾端应距射孔顶界 15 m 以上，油管挂以下 8 m 之内不能有油管接箍，偏心宽度应大于 35 mm。

7.3.3 气举找水管柱的尾端应距射孔顶界 15 m 以上，泵下工作筒规格的选定应保证其堵塞器能从泵中通过，且能顺利通过测试仪器。

7.3.4 杆柱上各井下工具和抽油杆接箍的生产运行位置应避开泄油器和复合管柱的变径接头。

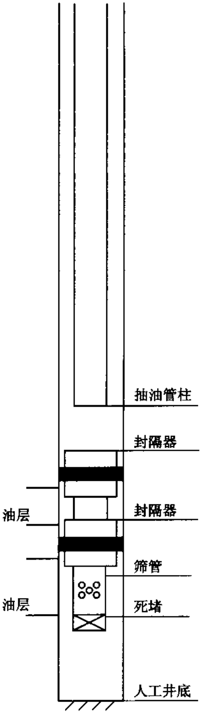


图 5

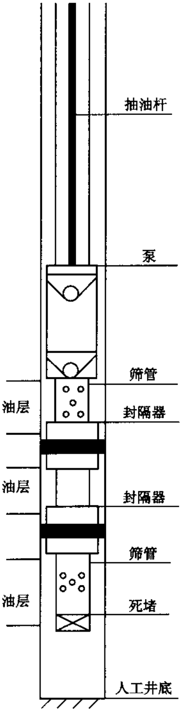


图 6

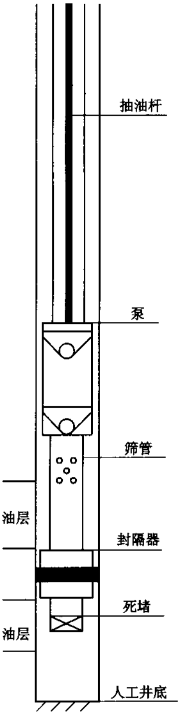


图 7

7.3.5 刮蜡器或扶正刮蜡器的限位块在抽油杆上的固定方式，应以不损害抽油杆为前提。

7.3.6 不支撑井底的丢手分采管柱应有卡瓦封隔器或卡瓦固定，不带卡瓦的支撑井底的丢手分采管柱在封堵层上下均应有封隔器进行防顶平衡。

7.3.7 使用丢手不压井（分采）管柱的井，抽油管柱不能压在丢手管柱上，应与其有 0.3m 以上的距离。

8 施工

8.1 施工设计

8.1.1 根据油井目前生产状况或地质方案编写施工设计书。若需要更改施工设计，必须由设计单位提出补充设计或设计变更通知单，经审批后方可实施。

8.1.2 施工设计书的格式及填写要求参见附录 D。

8.2 施工准备

按 SY/T 5587.5—2004 中的要求。

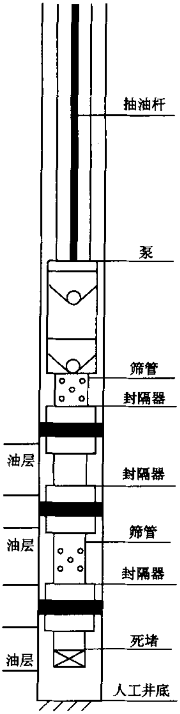


图 8

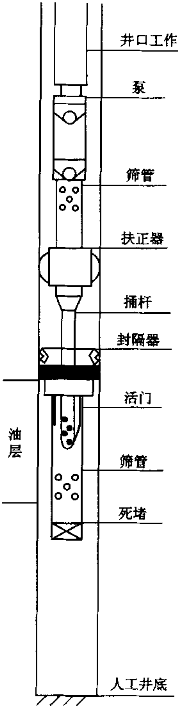


图 9

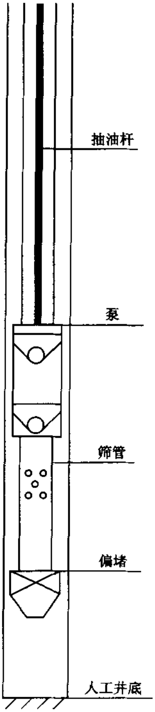


图 10

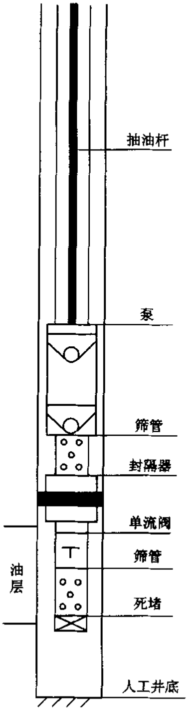


图 11

8.3 起下作业程序及技术要求

8.3.1 洗井

按 SY/T 5587.5—2004 中的要求。

8.3.2 压井

按 SY/T 5587.3—2004 中的要求。

8.3.3 起抽油杆柱

8.3.3.1 要做好井控工作，安装好井控装置。装有脱接器的井，起第一根抽油杆时要缓慢上提，以保证脱接器顺利脱开；装有开泄器的井，当开泄器接近泄油器时也要缓慢上提，以保证顺利打开泄油器。上提抽油杆柱遇阻时，不能盲目硬拔，应查明原因制定措施后再进行处理。

8.3.3.2 起抽油杆柱时各岗位要密切配合，防止造成抽油杆变形，防止造成井下落物。

8.3.3.3 平稳操作起完抽油杆及活塞。抽油杆桥要求使用 4 根油管搭成，每根油管至少使用 4 个桥座架起，起出的抽油杆在杆桥上每 10 根 1 组排列整齐，抽油杆悬空端长度不得大于 1.0m，抽油杆距地面高度不得小于 0.5m。

8.3.4　起管柱

按 SY/T 5587.5—2004 中的要求。

8.3.5　刮蜡、通井

按 SY/T 5587.5—2004 中的要求。

8.3.6　替喷

按 SY/T 5587.3—2004 中的要求。

8.3.7　探砂面、冲砂

按 SY/T 5587.5—2004 中的要求。

8.3.8　配管柱

8.3.8.1　用蒸汽清洗油管、抽油杆，确保下井油管、抽油杆及工具清洁。

8.3.8.2　螺纹损坏，杆体弯曲、接头或杆体磨损严重，或有其他变形的抽油杆不允许下井。螺纹损坏，管体有砂眼、孔洞、裂缝、磨损的油管不许允下井。必要时要检测油管和抽油杆疲劳强度。

8.3.8.3　73mm 普通油管使用 ϕ59mm×800mm 内径规通油管，89mm 油管使用 ϕ73mm×800mm 内径规通油管，不合格油管不允许下井。

8.3.8.4　油管和抽油杆要 3 丈量、3 对口，做好记录，3 次丈量结果下井管柱总长度误差小于 0.02%为合格。

8.3.8.5　组装下井工具做到设计、合格证、实物三对口，复核无差错后方可下井。

8.3.9　下管柱

按 SY/T 5587.5—2004 中的要求。

8.3.10　下抽油杆柱

8.3.10.1　抽油杆螺纹及接触端面必须清洗干净，加装抽油杆扶正器的位置、数量符合设计要求。

8.3.10.2　抽油杆上扣扭矩应符合表 4 的规定。

表 4　抽油杆上扣扭矩执行标准

抽油杆规格 mm	上紧矩，kN·m	
	应力为 245MPa	应力大于 245MPa
16	0.30	0.33
19	0.48	0.53
22	0.72	0.79
25	1.10	1.22
29	1.52	1.67

8.3.10.3　防止上扣扭矩过大，损坏抽油杆螺纹。

8.3.10.4　平稳缓慢下放，使活塞顺利进入泵筒。装有脱接器的井，对接好脱接器，对接后提抽油杆不能超高，防止脱接器脱开。装有井下开关的井，按照使用要求打开井下开关。

8.3.10.5　活塞坐进泵筒后，光杆伸入顶丝法兰以下长度不小于防冲距与最大冲程长度之和。活塞坐进泵筒后，驴头在下死点，确保光杆伸入悬绳器的长度不大于 0.3m。

8.3.10.6　下管柱期间严禁放喷。

8.3.11　试抽交井

8.3.11.1　装驴头对中井口，严防光杆弯曲，并按照设计要求对好防冲距。

8.3.11.2　试抽憋压达到 3 MPa～5MPa，稳压 15min，降压小于 0.3MPa 为合格，憋压不合格应查找原因。

8.3.11.3 倒流程，启抽。观察生产情况正常后交井。

8.4 编写施工总结

8.4.1 完工后及时编写施工总结。

8.4.2 施工总结格式参见附录E。

8.5 健康安全环保质量控制

按SY/T 6361—1998、SY/T 6362—1998和SY/T 5587.5—2004中的要求。

附录A

（资料性附录）

游梁式抽油机选型图绘制

A.1　游梁式抽油机选型图计算理论依据

标志抽油机使用范围的两个基本参数是下泵深度和泵的排量。

A.1.1　最大下泵深度的确定

抽油设备的最大下泵深度主要受到三个因素的限制：额定悬点载荷 $[P_{\max}]$、减速器额定扭矩 $[M_{\max}]$ 和抽油杆的应力强度。

A.1.1.1　由额定悬点载荷 $[P_{\max}]$ 所限制的最大下泵深度 $L_{\max}$ 按式（A.1）计算：

$$L_{\max}=\frac{[P_{\max}]}{\rho_{wL}g\ (A_p-A_{r1})\ +q_r\left(1+\frac{S_{\max}N_{\max}^2}{1790}\right)} \qquad \cdots\cdots\cdots\cdots\cdots\cdots\ (A.1)$$

A.1.1.2　由减速器额定扭矩 $[M_{\max}]$ 所限制的最大下泵深度 $L_{\max}$ 按式（A.2）计算：

$$L_{\max}=\frac{[M_{\max}]\ -300S_{\max}}{0.236S_{\max}\left[\rho_{wL}g\ (A_p-A_{r1})\ +2q_r\frac{S_{\max}N_{\max}^2}{1790}\right]} \qquad \cdots\cdots\cdots\cdots\ (A.2)$$

A.1.1.3　由抽油杆强度条件所限制的最大下泵深度 $L_{\max}$：选用修正的古德曼应力图（参见图 A.1）法进行计算。由此可以得出在非对称循环载荷作用下抽油杆的许用最大应力及许用应力范围，按式（A.3）、式（A.4）计算：

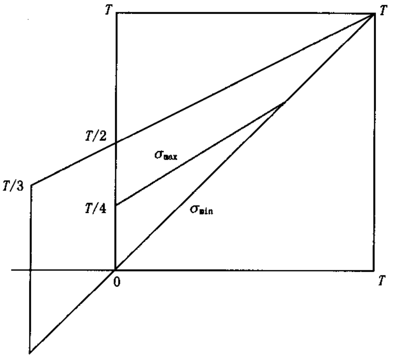


图 A.1　修正的古德曼应力图

$$\sigma_{rp,\max}=\ (aT+b\sigma_{r,\min})\ SF \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\ (A.3)$$

$$[\Delta\sigma]\ =\sigma_{rp,\max}-\sigma_{r,\min} \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\ (A.4)$$

对于组合杆柱采用等使用系数的原则来使各极杆柱顶端进行等强度设计计算，即：

$$\frac{\sigma_{\mathrm{rp,max,L}}}{aT + b\sigma_{\mathrm{r,min,L}}} = \frac{\sigma_{\mathrm{rp,max,L+1}}}{aT + b\sigma_{\mathrm{r,min,L+1}}} \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(A. 5)}$$

从而求得各级杆柱的最大下入深度以及整个杆柱系统的最大下泵深度。

A. 1. 2　最大排量计算

泵的最大排量按式（A. 6）计算：

$$Q_{\max} = 1440 A_{\mathrm{p}} S_{\mathrm{pmax}} N_{\max} \eta \qquad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(A. 6)}$$

其中：

$$S_{\mathrm{pmax}} = S_{\max} - \lambda + \lambda_i$$

$$\lambda = \frac{W_{\mathrm{L}} L_{\max}}{E} \left(\frac{1}{A_{\mathrm{r}}} + \frac{1}{A_{\mathrm{t}}} \right)$$

$$\lambda_i = \left(\frac{L_{\max}}{1915} \right)^2 \frac{S_{\max} N_{\max}^2}{1155}$$

对多级组合杆柱的计算公式，只需将 λ 计算式括号中的第一项进行相应的修正即可。

A. 2　游梁式抽油机选型图绘制方法

A. 2. 1　首先对 SY/T 5044—2003 中给出的 28 种抽油机，分别对额定悬点载荷相同且悬点最大冲程值不同的抽油机按最大悬点冲程值进行长、中、短分类组合。这里的分类不是绝对值的分类，而是一个为绘图和使用方便而进行的相对分类。对只有一种机型的 2 型和 6 型抽油机，则按照其最大冲程值和相邻机型最大冲程值的比值关系分别列入短冲程和中冲程分类组。对有 4 种规格型号的 5 型抽油机，则把其中的 5－2. 5－18 单独分类。

A. 2. 2　针对某一种抽油机给定的额定悬点载荷和额定扭矩值以及不同的杆柱组合与 GB/T 18607—2001 给出的 10 种泵径值相结合上机进行计算，由影响最大下泵深度的三个因素分别算得三个下泵深度值，取其中最小值来做绘图用的最大下泵深度值。对应不同泵径下的最大排量由式（A. 6）来计算求得。这两个值组成的抽油机选型图上的一个坐标点即为图中的抽油机最大适用范围线上（对应该泵径下）的一个拐点。

A. 2. 3　按照分类组合情况分别绘制选型图（参见图 A. 2～图 A. 5），对 16 和 18 型抽油机因使用很少，所以在绘图中为了图中曲线整体的协调性，则分别绘入图 A. 2 和图 A. 3 中。

A. 3　抽油机选型图计算取值

抽油机选型图在计算过程中，其有关参数取值如下：

$\rho_{\mathrm{wL}} = 950\ \mathrm{kg/m^3}$

$D_{\mathrm{ps}} = 200\ \mathrm{m}$

$E = 2.058 \times 10^{11}\ \mathrm{Pa}$

$T = 8 \times 10^{8}\ \mathrm{Pa}$

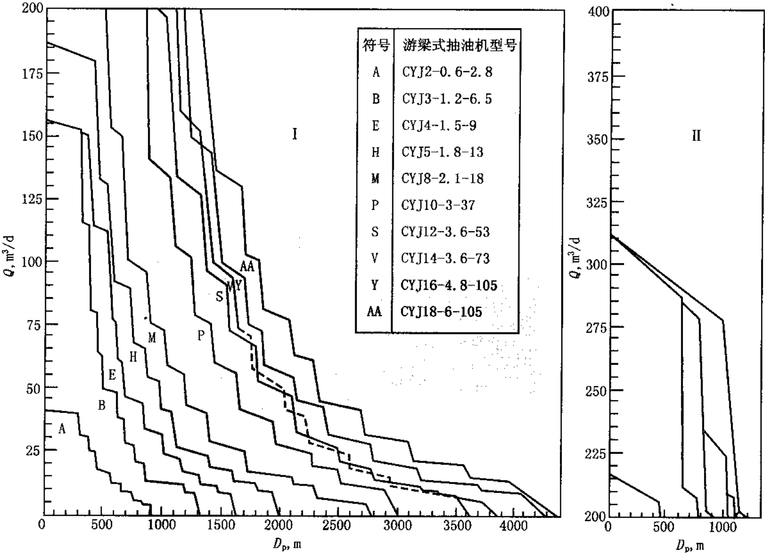
$SF = 0.9$

$\eta = 0.85$

在计算中假定油管柱已锚定。

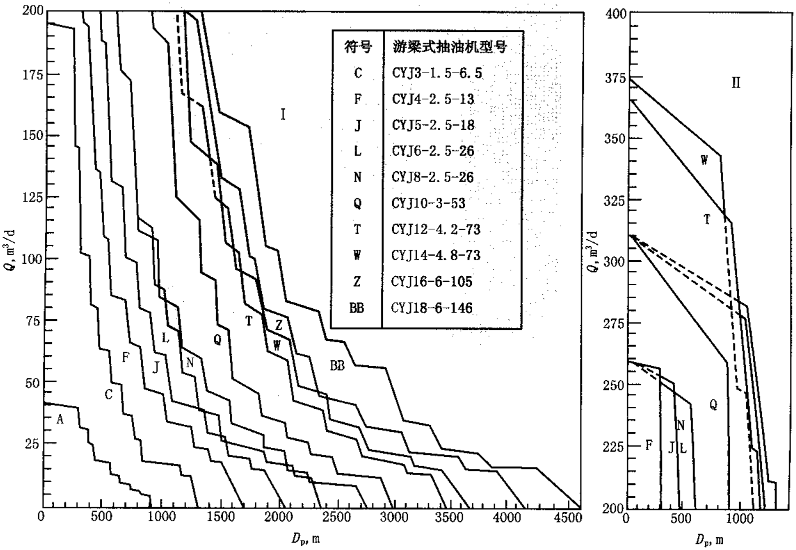
A. 4　最大冲次取值

计算中对不同机型的最大冲次取值列入表 A. 1 中。



符号	游梁式抽油机型号
A	CYJ2-0.6-2.8
B	CYJ3-1.2-6.5
E	CYJ4-1.5-9
H	CYJ5-1.8-13
M	CYJ8-2.1-18
P	CYJ10-3-37
S	CYJ12-3.6-53
V	CYJ14-3.6-73
Y	CYJ16-4.8-105
AA	CYJ18-6-105

图 A.2　游梁式抽油机选型图 A



符号	游梁式抽油机型号
C	CYJ3-1.5-6.5
F	CYJ4-2.5-13
J	CYJ5-2.5-18
L	CYJ6-2.5-26
N	CYJ8-2.5-26
Q	CYJ10-3-53
T	CYJ12-4.2-73
W	CYJ14-4.8-73
Z	CYJ16-6-105
BB	CYJ18-6-146

图 A.3　游梁式抽油机选型图 B

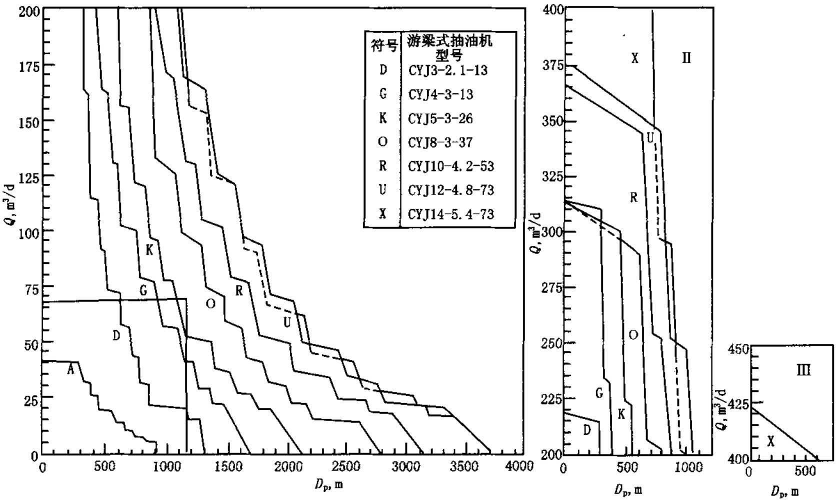


图 A.4 游梁式抽油机选型图 C

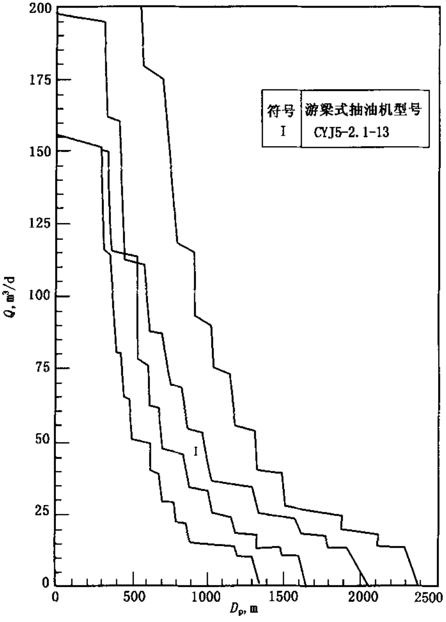


图 A.5 游梁式抽油机选型图 D

表 A.1　游梁式抽油机基本参数

序号	游梁式抽油机型号及规格	额定悬点载荷 10kN	光杆最大冲程 m	减速器额定扭矩 kN·m	最高冲次 min^{-1}
1	2-0.6-2.8	2	0.6	2.8	15
2	3-1.2-6.5	3	1.2	6.5	
3	3-1.5-6.5		1.5		
4	3-2.1-13		2.1	13	12
5	4-1.5-9	4	1.5	9.0	
6	4-2.5-13		2.5	13	
7	4-3-18		3.0	18	
8	5-1.8-13	5	1.8	13	
9	5-2.1-13		2.1		
10	5-2.5-18		2.5	18	
11	5-3-26		3.0	26	
12	6-2.5-26	6	2.5		
13	8-2.1-18	8	2.1	18	
14	8-2.5-26		2.5	26	
15	8-3-37		3.0	37	
16	10-3-37	10			
17	10-3-53			53	10
18	10-4.2-53	10	4.2	53	
19	12-3.6-53	12	3.6		
20	12-4.2-73		4.2	73	
21	12-4.8-73		4.8		9
22	14-3.6-73	14	3.6		
23	14-4.8-73		4.8		
24	14-5.4-73		5.4		
25	16-4.8-105	16	4.8	105	6
26	16-6-105		6.0		
27	18-6-105	18			
28	18-6-146			146	

A.5　游梁式抽油机选型示例

已知一油井含水为零，原油密度为 0.912 g/cm^3，动力粘度 1100 mPa·s，设计该井产量为 70 m^3/d，其相应所需下泵深度为 1150 m，对抽油机进行选型。

A.5.1　确定选型图：因该井原油较稠，故选择长冲程抽油机，确定图 A.4 为此井选型图。

A.5.2　在确定的选型图（图 A.4）上确定应选的抽油机型号。在横坐标轴上找出下泵深度 1150 m

的点，由此点作横坐标轴的垂线；再在纵坐标轴上找出和油井产量 70 m^3/d 对应的点，由此点作纵坐标轴的垂线。两垂线的交点落在 8－3－37 抽油机选择区域范围内，上选一个级别为 10－4.2－53 型抽油机。

附　录　B

（资料性附录）

抽油杆柱组合设计表

抽油杆柱组合设计表见表B.1。

表 B.1　抽油杆柱组合设计表

d_p mm	S m	杆柱代号	各种杆柱所占比例																											
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			L_{max} m	抽油杆直径 mm						L_{max} m	抽油杆直径 mm						L_{max} m	抽油杆直径 mm						L_{max} m	抽油杆直径 mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
32	≥1.6 ≤2.7	54	2363	—	—	—	—	64	36	2063	—	—	—	—	62	38	1793	—	—	—	—	59	41	1553	—	—	—	—	55	45
		64	2903	—	—	—	47	45	8	2573	—	—	—	47	41	12	2263	—	—	—	47	38	15	1973	—	—	—	45	35	19
		65	2843	—	—	—	47	53	—	2473	—	—	—	48	52	—	2123	—	—	—	47	53	—	1813	—	—	—	46	54	—
		76	3233	—	—	37	63	—	—	2803	—	—	39	61	—	—	2393	—	—	39	61	—	—	2023	—	—	38	62	—	—
		75	3943	—	—	57	30	13	—	3043	—	—	38	35	27	—	2653	—	—	39	33	28	—	2283	—	—	38	32	30	—
		87	3533	—	30	70	—	—	—	3053	—	32	68	—	—	—	2603	—	33	67	—	—	—	2183	—	33	67	—	—	—
		86	4418	—	47	26	27	—	—	3403	—	31	31	38	—	—	2953	—	33	29	38	—	—	2513	—	32	28	40	—	—
		85	4433	—	46	26	24	4	—	3573	—	31	30	26	13	—	3153	—	32	29	24	15	—	2753	—	33	28	22	17	—
		97	4933	45	21	34	—	—	—	3833	32	25	43	—	—	—	3323	34	24	42	—	—	—	2823	34	23	43	—	—	—
		96	5143	24	41	21	14	—	—	4563	46	21	19	14	—	—	3643	34	24	21	21	—	—	3163	35	23	20	22	—	—
		95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3773	34	24	21	16	5	—	3343	36	23	19	15	7	—
	>2.7 ≤3.3	54	2303	—	—	—	—	62	38	1973	—	—	—	—	59	41	1683	—	—	—	—	57	43	1414	—	—	—	—	53	47
		64	2833	—	—	—	46	45	9	2463	—	—	—	46	40	14	2113	—	—	—	45	37	18	1794	—	—	—	43	35	22
		65	2773	—	—	—	47	53	—	2353	—	—	—	46	54	—	1973	—	—	—	45	55	—	1634	—	—	—	43	57	—
		76	3153	—	—	37	63	—	—	2653	—	—	38	62	—	—	2203	—	—	37	63	—	—	1814	—	—	36	64	—	—

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																											
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
32	>2.7 ≤3.3	64	3353	—	—	—	35	37	28	2883	—	—	—	37	34	29	2443	—	—	—	36	33	31	2044	—	—	—	35	31	34
		76	3443	—	—	30	70	—	—	2893	—	—	31	69	—	—	2393	—	—	31	69	—	—	1954	—	—	31	69	—	—
		86	3763	—	28	30	42	—	—	3213	—	30	30	40	—	—	2703	—	30	28	42	—	—	2234	—	30	27	43	—	—
		85	3883	—	28	30	29	13	—	3383	—	30	29	26	15	—	2903	—	30	28	24	18	—	2444	—	30	27	23	20	—
		97	4223	29	24	47	—	—	—	3603	31	24	45	—	—	—	3023	32	24	44	—	—	—	2484	32	23	45	—	—	—
		96	4773	37	22	22	19	—	—	3883	31	24	22	23	—	—	3313	32	23	21	24	—	—	2774	33	22	19	26	—	—
		95	4773	37	22	22	19	—	—	3973	30	24	22	19	5	—	3463	31	23	21	17	8	—	2954	33	22	19	16	10	—
	>3.3 ≤4.2	54	2243	—	—	—	—	62	38	1863	—	—	—	—	57	43	1534	—	—	—	—	54	46	1284	—	—	—	—	51	49
		64	2753	—	—	—	45	44	11	2323	—	—	—	44	39	17	1924	—	—	—	42	36	22	1614	—	—	—	40	34	26
		65	2693	—	—	—	46	54	—	2213	—	—	—	45	55	—	1794	—	—	—	43	57	—	1464	—	—	—	40	60	—
		76	3053	—	—	36	64	—	—	2483	—	—	36	64	—	—	1994	—	—	36	64	—	—	1604	—	—	34	66	—	—
		75	3253	—	—	35	36	29	—	2703	—	—	35	34	31	—	2204	—	—	34	32	34	—	1814	—	—	33	30	37	—
		87	3333	—	30	70	—	—	—	2703	—	31	69	—	—	—	2154	—	30	70	—	—	—	1724	—	29	71	—	—	—
		86	3633	—	28	30	42	—	—	2993	—	29	29	42	—	—	2424	—	29	27	44	—	—	1954	—	28	26	46	—	—
		85	3763	—	27	30	29	14	—	3163	—	29	28	26	17	—	2614	—	28	27	24	21	—	2154	—	27	26	23	24	—
		97	4083	29	24	47	—	—	—	3353	30	24	46	—	—	—	2704	31	23	46	—	—	—	2164	30	22	48	—	—	—
		96	4323	28	23	24	25	—	—	3613	30	23	22	25	—	—	2954	30	22	21	27	—	—	2404	29	21	20	30	—	—
		95	4363	29	23	24	22	4	—	3713	28	23	22	19	8	—	3104	30	22	20	17	11	—	2584	29	21	19	17	14	—

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																									
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
32	>4.2 ≤5.0	54	2203	—	—	—	—	61	39	1813	—	—	—	—	56	44	1464	—	—	—	—	52	48	1214	—	—	—	—	49	51
		64	2713	—	—	—	45	43	12	2253	—	—	—	43	39	18	1844	—	—	—	41	36	23	1524	—	—	—	39	33	28
		65	2643	—	—	—	45	55	—	2133	—	—	—	44	56	—	1704	—	—	—	42	58	—	1374	—	—	—	39	61	—
		76	2993	—	—	36	64	—	—	2393	—	—	36	64	—	—	1884	—	—	35	65	—	—	1504	—	—	33	67	—	—
		75	3193	—	—	34	36	30	—	2603	—	—	35	33	32	—	2094	—	—	33	31	36	—	1694	—	—	32	29	39	—
		87	3273	—	30	70	—	—	—	2593	—	30	70	—	—	—	2034	—	29	71	—	—	—	1604	—	28	72	—	—	—
		86	3563	—	28	29	43	—	—	2873	—	29	29	42	—	—	2284	—	28	27	45	—	—	1824	—	27	26	47	—	—
		85	3693	—	27	29	29	15	—	3043	—	27	28	26	19	—	2474	—	28	26	24	22	—	2014	—	27	25	22	26	—
		97	4003	29	24	47	—	—	—	3213	30	23	47	—	—	—	2544	30	22	48	—	—	—	2004	29	21	50	—	—	—
		96	4233	27	23	24	26	—	—	3463	28	23	22	27	—	—	2784	30	22	20	28	—	—	2234	28	21	19	32	—	—
		95	4283	27	23	24	22	4	—	3583	29	22	21	19	9	—	2934	30	21	20	17	12	—	2404	29	20	19	17	15	—
	>5.0 ≤6.0	54	2143	—	—	—	—	60	40	1694	—	—	—	—	55	45	1354	—	—	—	—	51	49	1805	—	—	—	—	47	53
		64	2633	—	—	—	44	43	13	2104	—	—	—	42	38	20	1694	—	—	—	39	35	26	1365	—	—	—	37	33	30
		65	2553	—	—	—	45	55	—	1984	—	—	—	43	57	—	1554	—	—	—	41	59	—	1225	—	—	—	48	62	—
		76	2893	—	—	36	64	—	—	2224	—	—	35	65	—	—	1714	—	—	33	67	—	—	1335	—	—	32	68	—	—
		75	3083	—	—	34	35	31	—	2424	—	—	33	33	34	—	1904	—	—	32	30	38	—	1505	—	—	30	29	41	—
		78	3163	—	30	70	—	—	—	2414	—	30	70	—	—	—	1844	—	29	71	—	—	—	1415	—	28	72	—	—	—

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																									
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
32	>5.0 ≤6.0	86	3443	—	29	29	43	—	—	2674	—	28	28	44	—	—	2074	—	27	26	47	—	—	1605	—	26	25	49	—	—
		85	3583	—	27	28	28	16	—	2834	—	28	27	25	20	—	2244	—	26	25	24	25	—	1785	—	25	24	22	29	—
		97	3863	28	24	47	—	—	—	2984	29	23	48	—	—	—	2294	29	22	49	—	—	—	1765	28	21	51	—	—	—
		96	4093	27	23	23	26	—	—	3224	29	22	21	28	—	—	2514	28	21	20	31	—	—	1965	27	20	19	34	—	—
		95	4152	27	22	23	21	6	—	3334	28	22	21	19	10	—	2664	26	21	20	18	15	—	2125	27	20	18	17	18	—
38	≥1.6 ≤2.7	54	1923	—	—	—	—	73	27	1703	—	—	—	—	69	31	1493	—	—	—	—	65	35	1303	—	—	—	—	59	41
		65	2383	—	—	—	55	45	—	2083	—	—	—	54	46	—	1803	—	—	—	52	48	—	1553	—	—	—	—	49	51
		64	2383	—	—	—	55	45	—	2083	—	—	—	54	46	0	1863	—	—	—	51	39	10	1643	—	—	—	48	37	15
		76	2783	—	—	42	58	—	—	2413	—	—	43	57	—	—	2073	—	—	43	57	—	—	1763	—	—	41	59	—	—
		75	2873	—	—	42	41	17	—	2543	—	—	42	38	20	—	2223	—	—	42	35	23	—	1933	—	—	41	33	26	—
		87	3103	—	34	66	—	—	—	2693	—	36	64	—	—	—	2293	—	36	64	—	—	—	1933	—	35	65	—	—	—
		86	3763	—	54	28	18	—	—	2913	—	35	33	32	—	—	2533	—	36	31	33	—	—	2173	—	36	29	35	—	—
		85	3763	—	54	28	18	0	—	2973	—	34	33	27	6	—	2633	—	36	31	24	9	—	2303	—	35	29	23	13	—
		98	3523	35	65	—	—	—	—	3063	37	63	—	—	—	—	2613	37	63	—	—	—	—	2193	37	63	—	—	—	—
		97	4343	51	23	26	—	—	—	3353	35	27	38	—	—	—	2903	37	26	37	—	—	—	2483	37	25	38	—	—	—
		96	4363	50	23	22	5	—	—	3513	35	26	24	15	—	—	3103	38	25	21	16	—	—	2693	38	24	20	18	—	—

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																											
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			L_{max} m	抽油杆直径 mm						L_{max} m	抽油杆直径 mm						L_{max} m	抽油杆直径 mm						L_{max} m	抽油杆直径 mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
38	>2.7 ≤3.3	54	1893	—	—	—	—	73	27	1633	—	—	—	—	66	34	1413	—	—	—	—	62	38	1204	—	—	—	—	58	42
		65	2333	—	—	—	54	46	—	1993	—	—	—	52	48	—	1683	—	—	—	49	51	—	1414	—	—	—	46	54	—
		64	—	—	—	—	—	—	—	2023	—	—	—	51	42	7	1753	—	—	—	48	39	13	1514	—	—	—	46	36	18
		76	2713	—	—	42	58	—	—	2293	—	—	42	58	—	—	1923	—	—	40	60	—	—	1594	—	—	38	62	—	—
		75	2813	—	—	41	41	18	—	2423	—	—	41	37	22	—	2073	—	—	40	34	26	—	1754	—	—	38	32	30	—
		87	3023	—	34	66	—	—	—	2543	—	35	65	—	—	—	2113	—	34	66	—	—	—	1744	—	33	67	—	—	—
		86	3223	—	33	34	34	—	—	2763	—	33	32	35	—	—	2333	—	33	30	37	—	—	1954	—	32	28	40	—	—
		85	3253	—	32	34	30	4	—	2833	—	34	32	26	8	—	2443	—	33	29	25	13	—	2084	—	32	28	24	16	—
		98	3433	34	66	—	—	—	—	2893	36	64	—	—	—	—	2403	36	64	—	—	—	—	1964	35	65	—	—	—	—
		97	3703	33	27	40	—	—	—	3163	34	26	40	—	—	—	2663	35	25	40	—	—	—	2204	34	24	42	—	—	—
		96	3823	33	26	26	15	—	—	3323	34	26	23	17	—	—	2843	35	25	21	19	—	—	2394	35	23	20	22	—	—
		95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2903	35	24	21	16	4	—	2494	34	23	20	16	7	—
	>3.3 ≤4.2	54	1843	—	—	—	—	71	29	1553	—	—	—	—	63	37	1304	—	—	—	—	59	41	1104	—	—	—	—	55	45
		65	2263	—	—	—	53	47	—	1873	—	—	—	50	50	—	1544	—	—	—	46	54	—	1284	—	—	—	43	57	—
		64	—	—	—	—	—	—	—	1923	—	—	—	49	41	10	1624	—	—	—	46	38	16	1374	—	—	—	42	36	22
		76	2623	—	—	41	59	—	—	2153	—	—	40	60	—	—	1744	—	—	38	62	—	—	1424	—	—	37	63	—	—
		75	2723	—	—	40	40	20	—	2283	—	—	39	36	25	—	1894	—	—	38	33	29	—	1574	—	—	36	31	33	—

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																											
			$2\text{min}^{-1}\leqslant n\leqslant 5\text{min}^{-1}$							$5\text{min}^{-1}< n\leqslant 8\text{min}^{-1}$							$8\text{min}^{-1}< n\leqslant 11\text{min}^{-1}$							$11\text{min}^{-1}< n\leqslant 15\text{min}^{-1}$						
			L_{max} m	抽油杆直径 mm						L_{max} m	抽油杆直径 mm						L_{max} m	抽油杆直径 mm						L_{max} m	抽油杆直径 mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
38	>3.3 ≤4.2	87	2923	—	34	66	—	—	—	2383	—	34	66	—	—	—	1914	—	33	67	—	—	—	1554	—	31	69	—	—	—
		86	3123	—	32	33	35	—	—	2583	—	32	31	37	—	—	2114	—	31	29	40	—	—	1734	—	30	27	43	—	—
		85	3153	—	32	33	30	5	—	2663	—	32	30	27	11	—	2224	—	31	28	25	16	—	1864	—	30	27	23	20	—
		98	3323	34	66	—	—	—	—	2703	35	65	—	—	—	—	2164	34	66	—	—	—	—	1734	33	67	—	—	—	—
		97	3573	32	27	41	—	—	—	2953	33	25	42	—	—	—	2394	33	24	43	—	—	—	1934	32	23	45	—	—	—
		96	3703	32	26	26	16	—	—	3103	33	25	23	19	—	—	2564	32	24	21	23	—	—	2114	32	22	20	26	—	—
		95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2634	32	24	21	17	6	—	2214	31	22	20	17	10	—
	>4.2 ≤5.0	54	1813	—	—	—	—	69	31	1513	—	—	—	—	62	38	1244	—	—	—	—	57	43	1044	—	—	—	—	52	48
		65	2223	—	—	—	52	48	—	1813	—	—	—	49	51	—	1474	—	—	—	45	55	—	1204	—	—	—	42	58	—
		64	—	—	—	—	—	—	—	1873	—	—	—	48	41	11	1554	—	—	—	44	38	18	1304	—	—	—	41	35	24
		76	2573	—	—	41	59	—	—	2073	—	—	40	60	—	—	1664	—	—	37	63	—	—	1344	—	—	35	65	—	—
		75	2683	—	40	40	20	—	—	2203	—	—	38	36	26	—	1804	—	—	37	33	30	—	1484	—	—	34	30	36	—
		87	2873	—	33	67	—	—	—	2023	—	33	67	—	—	—	1814	—	31	69	—	—	—	1444	—	30	70	—	—	—
		86	3063	—	32	33	35	—	—	2493	—	31	30	39	—	—	2004	—	30	28	40	—	—	1614	—	29	27	44	—	—
		85	3103	—	32	32	30	6	—	2583	—	32	30	26	12	—	2114	—	29	28	25	18	—	1744	—	28	26	24	22	—
		98	3263	34	66	—	—	—	—	2593	34	66	—	—	—	—	2044	34	66	—	—	—	—	1614	32	68	—	—	—	—
		97	3503	32	26	42	—	—	—	2833	33	25	42	—	—	—	2254	32	24	44	—	—	—	1804	31	22	47	—	—	—

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																										
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
38	>1.2 ≤5.0	96	3633	32	26	25	17	—	—	2993	32	24	23	21	—	—	2424	32	23	21	24	—	—	1974	30	22	20	28	—	—
		95	—	—	—	—	—	—	—	3023	33	24	22	18	3	—	2504	31	23	21	17	8	—	2074	30	23	20	17	12	—
	>5.0 ≤6.0	54	1763	—	—	—	—	68	32	1433	—	—	—	—	60	40	1164	—	—	—	—	54	46	955	—	—	—	—	50	50
		65	2163	—	—	—	51	49	—	1713	—	—	—	47	53	—	1354	—	—	—	44	56	—	1085	—	—	—	41	59	—
		64	—	—	—	—	—	—	—	1773	—	—	—	46	40	14	1444	—	—	—	42	37	21	1185	—	—	—	39	35	26
		76	2493	—	—	40	60	—	—	1943	—	—	38	62	—	—	1514	—	—	36	64	—	—	1195	—	—	33	67	—	—
		75	2603	—	—	40	38	22	—	2083	—	—	37	35	28	—	1654	—	—	35	32	33	—	1325	—	—	32	30	38	—
		87	2773	—	33	67	—	—	—	2143	—	32	68	—	—	—	1654	—	30	70	—	—	—	1285	—	29	71	—	—	—
		86	2963	—	31	32	37	—	—	2333	—	30	30	40	—	—	1824	—	29	28	43	—	—	1445	—	28	26	46	—	—
		85	3013	—	31	32	29	8	—	2423	—	30	29	26	15	—	1944	—	29	27	24	20	—	1565	—	27	26	23	24	—
		98	3153	34	66	—	—	—	—	2423	33	67	—	—	—	—	1854	32	68	—	—	—	—	1435	31	69	—	—	—	—
		97	3393	32	26	42	—	—	—	2643	31	25	44	—	—	—	2044	31	23	46	—	—	—	1595	29	22	49	—	—	—
		96	3513	31	25	25	19	—	—	2803	32	24	22	22	—	—	2204	31	22	21	27	—	—	1755	28	21	19	30	—	—
		95	—	—	—	—	—	—	—	2845	31	24	22	18	5	—	2294	30	22	20	17	10	—	1855	29	20	19	17	15	—
44	≥1.6 ≤2.7	54	1603	—	—	—	—	83	17	1423	—	—	—	—	75	25	1263	—	—	—	—	69	31	1123	—	—	—	—	64	36
		65	2013	—	—	—	62	38	—	1773	—	—	—	59	41	—	1543	—	—	—	55	45	—	1343	—	—	—	52	48	—
		64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1393	—	—	—	51	38	11

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																											
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
44	≥1.6 ≤2.7	76	2393	—	—	48	52	—	—	2083	—	—	48	52	—	—	1803	—	—	46	54	—	—	1553	—	—	43	57	—	—
		75	2423	—	—	47	45	8	—	2153	—	—	48	39	13	—	1893	—	—	46	36	18	—	1663	—	—	44	34	22	—
		87	2723	—	39	61	—	—	—	2363	—	39	61	—	—	—	2023	—	39	61	—	—	—	1723	—	37	63	—	—	—
		86	2843	—	38	38	24	—	—	2503	—	39	35	26	—	—	2183	—	38	33	29	—	—	1893	—	37	31	32	—	—
		85	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2233	—	39	32	24	5	—	1963	—	37	31	23	9	—
		98	3143	39	61	—	—	—	—	2733	40	60	—	—	—	—	2333	40	60	—	—	—	—	1973	39	61	—	—	—	—
		97	3833	59	25	16	—	—	—	2933	38	29	32	—	—	—	2553	40	27	33	—	—	—	2183	39	26	35	—	—	—
		96	—	—	—	—	—	—	—	3003	39	29	24	9	—	28	2653	39	27	22	12	—	—	2323	40	25	20	15	—	—
	>2.7 ≤3.3	54	1573	—	—	—	—	81	19	1373	—	—	—	—	72	—	1203	—	—	—	—	66	34	1044	—	—	—	—	61	39
		65	1973	—	—	—	61	39	—	1703	—	—	—	58	42	—	1453	—	—	—	53	47	—	1244	—	—	—	50	50	—
		64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1453	—	—	—	48	42	10	1264	—	—	—	44	40	16
		76	2333	—	—	47	53	—	—	1993	—	—	46	54	—	—	1683	—	—	43	57	—	—	1414	—	—	41	59	—	—
		75	2373	—	—	47	44	9	—	2063	—	—	45	39	16	—	1773	—	—	43	36	21	—	1524	—	—	41	33	26	—
		87	2653	—	38	62	—	—	—	2243	—	38	62	—	—	—	1883	—	37	63	—	—	—	1564	—	35	65	—	—	—
		86	2773	—	37	37	26	—	—	1383	—	37	34	29	—	—	2083	—	36	32	32	—	—	1714	—	34	30	36	—	—
		85	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2083	—	36	32	24	8	—	1794	—	34	30	24	12	—
		98	3063	38	62	—	—	—	—	2583	39	61	—	—	—	—	2153	38	62	—	—	—	—	1784	37	63	—	—	—	—

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																											
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			L_{max} m	抽油杆直径 mm						L_{max} m	抽油杆直径 mm						L_{max} m	抽油杆直径 mm						L_{max} m	抽油杆直径 mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
44	>2.7 ≤3.3	97	3243	37	30	33	—	—	—	2773	38	28	34	—	—	—	2353	38	26	36	—	—	—	1964	36	25	39	—	—	—
		96	3283	37	29	27	7	—	—	2863	38	28	23	11	—	—	2463	37	26	22	15	—	—	2094	36	24	21	19	—	—
	>3.3 ≤4.2	54	1543	—	—	—	—	79	21	1313	—	—	—	—	69	31	1114	—	—	—	—	62	38	964	—	—	—	—	58	42
		65	1923	—	—	—	59	41	—	1613	—	—	—	55	45	—	1344	—	—	—	51	49	—	1134	—	—	—	46	54	—
		64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1344	—	—	—	44	42	14	1194	—	—	—	45	37	18
		76	2273	—	—	46	54	—	—	1873	—	—	44	56	—	—	1544	—	—	41	59	—	—	1274	—	—	38	62	—	—
		75	2313	—	—	46	43	11	—	1953	—	—	43	38	19	—	1634	—	—	41	35	24	—	1384	—	—	37	33	30	—
		87	2573	—	37	63	—	—	—	2103	—	37	63	—	—	—	1714	—	35	65	—	—	—	1394	—	33	67	—	—	—
		86	2693	—	37	36	27	—	—	2243	—	35	33	31	—	—	1854	—	33	31	36	—	—	1534	—	32	29	39	—	—
		85	—	—	—	—	—	—	—	2273	—	36	33	26	6	—	1914	—	34	30	25	11	—	1624	—	32	28	24	16	—
		98	2963	38	62	—	—	—	—	2423	38	62	—	—	—	—	1954	36	64	—	—	—	—	1584	35	65	—	—	—	—
		97	3133	36	29	35	—	—	—	2603	37	27	36	—	—	—	2124	35	25	40	—	—	—	1744	33	24	43	—	—	—
		96	3183	36	29	27	8	—	—	2693	36	27	23	14	—	—	2244	35	25	22	18	—	—	1864	31	23	21	25	—	—
	≥5.0 <4.2	54	1523	—	—	—	—	78	22	1283	—	—	—	—	68	32	1074	—	—	—	—	61	39	914	—	—	—	—	55	45
		65	1893	—	—	—	59	41	—	1563	—	—	—	53	47	—	1284	—	—	—	48	52	—	1074	—	—	—	44	56	—
		64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1314	—	—	—	46	40	14	1134	—	—	—	44	37	19
		76	2233	—	—	46	54	—	—	1813	—	—	43	57	—	—	1464	—	—	40	60	—	—	1204	—	—	37	63	—	—
		75	2273	—	—	45	43	12	—	1893	—	—	41	38	21	—	1564	—	—	39	35	26	—	1304	—	—	37	32	31	—

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																											
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm						$L_{\max}$ m	抽油杆直径 mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
44	>4.2 ≤5.0	87	2523	—	37	63	—	—	—	2033	—	35	65	—	—	—	1624	—	34	66	—	—	—	1314	—	31	69	—	—	—
		86	2643	—	36	36	28	—	—	2163	—	34	33	33	—	—	1764	—	32	30	38	—	—	1444	—	30	28	42	—	—
		85	—	—	—	—	—	—	—	2203	—	35	32	26	7	—	1834	—	32	30	25	13	—	1534	—	31	28	23	18	—
		98	2903	37	63	—	—	—	—	2333	37	63	—	—	—	—	1844	36	64	—	—	—	—	1474	34	66	—	—	—	—
		97	3073	36	29	35	—	—	—	2503	35	27	38	—	—	—	2014	34	25	41	—	—	—	1634	33	23	44	—	—	—
	>5.0 ≤6.0	96	3133	36	29	26	9	—	—	2593	35	26	24	15	—	—	2124	34	24	22	20	—	—	1754	31	23	21	25	—	—
		54	1483	—	—	—	—	76	24	1214	—	—	—	—	65	35	1014	—	—	—	—	59	41	835	—	—	—	—	53	47
		65	1843	—	—	—	58	42	—	1474	—	—	—	52	48	—	1194	—	—	—	46	54	—	975	—	—	—	43	57	—
		64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1244	—	—	—	44	39	17	1005	—	—	—	36	39	25
		76	2163	—	—	45	55	—	—	1704	—	—	42	58	—	—	1354	—	—	38	62	—	—	1085	—	—	35	65	—	—
		75	2213	—	—	44	42	14	—	1784	—	—	41	36	23	—	1444	—	—	36	34	30	—	1185	—	—	35	31	34	—
		87	2443	—	36	64	—	—	—	1904	—	35	65	—	—	—	1484	—	32	68	—	—	—	1175	—	30	70	—	—	—
		86	2563	—	35	36	29	—	—	2034	—	33	32	35	—	—	1614	—	31	29	40	—	—	1295	—	29	27	44	—	—
		85	—	—	—	—	—	—	—	2084	—	33	31	26	9	—	1694	—	31	28	25	16	—	1385	—	29	26	24	21	—
		98	2813	37	63	—	—	—	—	2174	36	64	—	—	—	—	1684	34	66	—	—	—	—	1315	32	68	—	—	—	—
		97	2973	35	28	37	—	—	—	2334	34	26	40	—	—	—	1834	33	24	43	—	—	—	1455	31	23	46	—	—	—
		96	3043	35	28	26	11	—	—	2434	35	25	23	17	—	—	1954	33	23	21	23	—	—	1565	31	22	20	27	—	—
		95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1984	30	24	21	18	7	—	1635	31	21	20	17	11	—

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																					
			2min^{-1}≤n≤5min^{-1}						5min^{-1}<n≤8min^{-1}						8min^{-1}<n≤11min^{-1}						11min^{-1}<n≤15min^{-1}					
			L_{max} m	抽油杆直径 mm					L_{max} m	抽油杆直径 mm					L_{max} m	抽油杆直径 mm					L_{max} m	抽油杆直径 mm				
				29	25	22	19	16		29	25	22	19	16		29	25	22	19	16		29	25	22	19	16
56	≥1.6 ≤2.7	65	1493	—	—	—	77	23	1324	—	—	—	70	30	1174	—	—	—	64	36	1035	—	—	—	59	41
		76	1813	—	—	60	40	—	1584	—	—	56	44	—	1394	—	—	53	47	—	1215	—	—	49	51	—
		75	—	—	—	—	—	—	—	—	—	—	—	—	1424	—	—	53	38	9	1255	—	—	48	37	15
		87	2113	—	48	52	—	—	1844	—	46	54	—	—	1594	—	44	56	—	—	1375	—	41	59	—	—
		86	2143	—	37	44	9	—	1894	—	46	39	15	—	1664	—	44	35	21	—	1455	—	41	34	25	—
		98	2503	47	53	—	—	—	2174	47	53	—	—	—	1874	45	54	—	—	—	1605	43	57	—	—	—
		97	2563	46	35	19	—	—	2264	46	32	22	—	—	1974	45	29	26	—	—	1715	44	27	29	—	—
	>2.7 ≤3.3	65	1463	—	—	—	74	26	1274	—	—	—	66	34	1114	—	—	—	60	40	975	—	—	—	55	45
		76	1773	—	—	58	42	—	1524	—	—	54	46	—	1314	—	—	50	50	—	1125	—	—	45	55	—
		75	—	—	—	—	—	—	—	—	—	—	—	—	1354	—	—	49	38	13	1175	—	—	44	37	19
		87	2063	—	47	53	—	—	1764	—	44	55	—	—	1494	—	41	59	—	—	1265	—	39	61	—	—
		86	2093	—	46	43	11	—	1814	—	44	38	18	—	1574	—	42	34	24	—	1355	—	39	32	29	—
		98	2443	46	54	—	—	—	2074	45	55	—	—	—	1744	43	57	—	—	—	1465	41	59	—	—	—
		97	2503	46	34	20	—	—	2154	44	31	25	—	—	1854	43	29	29	—	—	1575	40	27	33	—	—
		96	—	—	—	—	—	—	—	—	—	—	—	—	1884	42	28	22	8	—	1625	40	26	22	12	—
	>3.3 ≤4.2	65	1433	—	—	—	73	27	1224	—	—	—	64	36	1045	—	—	—	57	43	896	—	—	—	52	48
		76	1733	—	—	57	43	—	1454	—	—	52	48	—	1215	—	—	46	54	—	1026	—	—	43	57	—

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																							
			$2\text{min}^{-1}\leqslant n\leqslant 5\text{min}^{-1}$						$5\text{min}^{-1}< n\leqslant 8\text{min}^{-1}$						$8\text{min}^{-1}< n\leqslant 11\text{min}^{-1}$						$11\text{min}^{-1}< n\leqslant 15\text{min}^{-1}$					
			$L_{\max}$ m	抽油杆直径 mm					$L_{\max}$ m	抽油杆直径 mm					$L_{\max}$ m	抽油杆直径 mm					$L_{\max}$ m	抽油杆直径 mm				
				29	25	22	19	16		29	25	22	19	16		29	25	22	19	16		29	25	22	19	16
56	>3.3 ≤4.2	75	—	—	—	—	—	—	1474	—	—	51	41	8	1255	—	—	46	37	17	1086	—	—	42	36	22
		87	2003	—	45	55	—	—	1664	—	43	57	—	—	1375	—	39	61	—	—	1146	—	37	63	—	—
		86	2043	—	45	42	13	—	1724	—	42	37	21	—	1455	—	39	34	27	—	1226	—	35	32	33	—
		98	2363	45	55	—	—	—	1944	43	57	—	—	—	1595	41	59	—	—	—	1316	38	62	—	—	—
		97	2433	44	34	22	—	—	2034	42	30	28	—	—	1695	40	28	32	—	—	1416	38	25	37	—	—
		96	—	—	—	—	—	—	2054	42	30	23	5	—	1754	30	28	22	11	—	1476	37	25	22	16	—
	>4.2 ≤5.0	65	1413	—	—	—	71	29	1194	—	—	—	62	38	1005	—	—	—	55	45	847	—	—	—	50	50
		76	1703	—	—	56	44	—	1414	—	—	50	50	—	1165	—	—	45	55	—	967	—	—	41	59	—
		75	—	—	—	—	—	—	1434	—	—	50	40	10	1215	—	—	45	37	18	1027	—	—	42	34	24
		87	1973	—	45	55	—	—	1614	—	41	59	—	—	1315	—	38	62	—	—	1077	—	35	65	—	—
		86	2013	—	45	41	14	—	1674	—	41	36	23	—	1395	—	38	33	29	—	1157	—	34	31	35	—
		98	2323	45	55	—	—	—	1884	42	58	—	—	—	1525	39	61	—	—	—	1237	37	63	—	—	—
		97	2393	44	33	23	—	—	1974	42	29	29	—	—	1625	39	27	34	—	—	1327	35	26	39	—	—
		96	—	—	—	—	—	—	1994	40	30	24	6	—	1665	38	26	23	13	—	1397	36	26	21	17	—
	>5.0 ≤6.0	65	1374	—	—	—	69	31	1135	—	—	—	60	40	936	—	—	—	53	47	778	—	—	—	48	52
		76	1654	—	—	55	45	—	1335	—	—	48	52	—	1086	—	—	44	56	—	888	—	—	40	60	—
		75	—	—	—	—	—	—	1365	—	—	48	40	12	1136	—	—	42	37	21	938	—	—	38	34	28

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																							
			$2\text{min}^{-1}\leqslant n\leqslant 5\text{min}^{-1}$						$5\text{min}^{-1}<n\leqslant 8\text{min}^{-1}$						$8\text{min}^{-1}<n\leqslant 11\text{min}^{-1}$						$11\text{min}^{-1}<n\leqslant 15\text{min}^{-1}$					
			$L_{\max}$ m	抽油杆直径 mm					$L_{\max}$ m	抽油杆直径 mm					$L_{\max}$ m	抽油杆直径 mm					$L_{\max}$ m	抽油杆直径 mm				
				29	25	22	19	16		29	25	22	19	16		29	25	22	19	16		29	25	22	19	16
56	>5.0 ≤6.0	87	1914	—	44	56	—	—	1515	—	40	60	—	—	1216	—	36	63	—	—	978	—	34	66	—	—
		86	1954	—	44	40	16	—	1585	—	39	36	25	—	1286	—	35	32	33	—	1058	—	33	29	38	—
		98	2244	44	56	—	—	—	1765	41	59	—	—	—	1396	37	63	—	—	—	1108	35	65	—	—	—
		97	2324	44	32	24	—	—	1855	40	29	31	—	—	1486	36	26	38	—	—	1198	33	25	42	—	—
		96	—	—	—	—	—	—	1885	40	29	23	8	—	1546	37	25	23	15	—	1268	34	24	21	21	—
70	≥1.6 ≤2.7	76	1363	—	—	72	28	—	1214	—	—	65	35	—	1084	—	—	60	40	—	955	—	—	54	46	—
		87	1613	—	58	42	—	—	1424	—	54	46	—	—	1254	—	49	51	—	—	1095	—	45	55	—	—
		86	—	—	—	—	—	—	1434	—	54	40	6	—	1284	—	50	38	12	—	1135	—	46	35	19	—
		98	1943	57	43	—	—	—	1704	55	45	—	—	—	1484	51	49	—	—	—	1295	47	53	—	—	—
		97	1953	57	38	5	—	—	1734	55	33	12	—	—	1534	51	31	18	—	—	1345	46	30	21	—	—
	>2.7 ≤3.3	76	1343	—	—	71	29	—	1174	—	—	63	37	—	1025	—	—	56	44	—	905	—	—	51	49	—
		87	1583	—	56	44	—	—	1374	—	52	48	—	—	1185	—	48	52	—	—	1025	—	43	57	—	—
		86	—	—	—	—	—	—	1384	—	51	40	9	—	1215	—	47	37	16	—	1065	—	42	35	23	—
		98	1903	56	44	—	—	—	1634	52	48	—	—	—	1395	48	52	—	—	—	1195	44	56	—	—	—
		97	1913	55	38	7	—	—	1664	51	34	15	—	—	1445	49	30	21	—	—	1255	44	29	27	—	—
	>3.3 ≤4.2	76	—	—	—	—	—	—	1124	—	—	59	41	—	965	—	—	52	48	—	836	—	—	48	52	—
		87	1543	—	55	45	—	—	1304	—	48	52	—	—	1105	—	43	57	—	—	946	—	41	59	—	—

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																							
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$						$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$						$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$						$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$					
			L_{max} m	抽油杆直径 mm					L_{max} m	抽油杆直径 mm					L_{max} m	抽油杆直径 mm					L_{max} m	抽油杆直径 mm				
				29	25	22	19	16		29	25	22	19	16		29	25	22	19	16		29	25	22	19	16
70	>3.3 ≤4.2	86	—	—	—	—	—	—	1324	—	48	40	12	—	1145	—	44	36	20	—	986	—	41	33	26	—
		98	1853	55	45	—	—	—	1554	50	50	—	—	—	1295	46	54	—	—	—	1086	41	59	—	—	—
		97	1873	54	37	9	—	—	1584	49	33	18	—	—	1355	45	30	25	—	—	1146	41	28	31	—	—
	>1.2 ≤5.0	76	1294	—	—	68	32	—	1094	—	—	57	43	—	926	—	—	50	50	—	797	—	—	46	54	—
		87	1524	—	55	45	—	—	1274	—	48	52	—	—	1066	—	43	57	—	—	897	—	39	61	—	—
		86	—	—	—	—	—	—	1294	—	47	39	14	—	1096	—	41	36	23	—	937	—	38	33	29	—
		98	1814	54	46	—	—	—	1504	49	51	—	—	—	1236	44	56	—	—	—	1207	40	60	—	—	—
		97	1834	53	37	10	—	—	1544	48	32	20	—	—	1296	44	29	27	—	—	1087	39	28	33	—	—
	>5.0 ≤6.0	76	1264	—	—	66	34	—	1045	—	—	55	45	—	867	—	—	47	53	—	729	—	—	43	57	—
		87	1484	—	54	46	—	—	1205	—	45	55	—	—	987	—	41	59	—	—	819	—	38	62	—	—
		86	—	—	—	—	—	—	1235	—	45	38	17	—	1027	—	40	35	25	—	859	—	36	33	31	—
		98	1774	53	47	—	—	—	1425	46	54	—	—	—	1147	42	58	—	—	—	939	39	61	—	—	—
		97	1794	52	36	12	—	—	1465	46	31	23	—	—	1207	42	28	30	—	—	999	38	26	36	—	—
83	≥1.6 ≤2.7	87	1294	—	68	32	—	—	1154	—	60	40	—	—	1025	—	54	46	—	—	916	—	50	50	—	—
		86	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	926	—	48	38	14	—
		98	1564	66	34	—	—	—	1394	62	38	—	—	—	1225	56	44	—	—	—	1076	52	48	—	—	—
		97	—	—	—	—	—	—	1394	60	35	5	—	—	1245	56	32	12	—	—	1116	52	30	18	—	—

表 B.1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																							
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$						$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$						$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$						$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$					
			$L_{\max}$ m	抽油杆直径 mm					$L_{\max}$ m	抽油杆直径 mm					$L_{\max}$ m	抽油杆直径 mm					$L_{\max}$ m	抽油杆直径 mm				
				29	25	22	19	16		29	25	22	19	16		29	25	22	19	16		29	25	22	19	16
83	>2.7 ≤3.3	87	1247	—	66	34	—	—	1115	—	58	42	—	—	967	—	52	48	—	—	857	—	46	54	—	—
		86	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	867	—	42	38	20	—
		98	1544	66	34	—	—	—	1335	58	42	—	—	—	1156	52	48	—	—	—	1007	49	51	—	—	—
		97	—	—	—	—	—	—	1345	58	35	7	—	—	1186	53	32	15	—	—	1047	49	30	21	—	—
	>3.3 ≤4.2	87	1244	—	63	37	—	—	1075	—	56	44	—	—	917	—	48	52	—	—	798	—	44	56	—	—
		86	—	—	—	—	—	—	—	—	—	—	—	—	917	—	43	41	16	—	808	—	39	37	24	—
		98	1504	63	37	—	—	—	1275	55	45	—	—	—	1087	51	49	—	—	—	928	45	55	—	—	—
		97	—	—	—	—	—	—	1295	55	34	11	—	—	1117	49	32	19	—	—	968	45	30	25	—	—
	>4.2 ≤5.0	87	1234	—	63	37	—	—	1045	—	53	47	—	—	887	—	46	54	—	—	760	—	42	58	—	—
		86	1234	—	63	37	0	—	1045	—	53	47	0	—	897	—	43	39	18	—	760	—	42	58	—	—
		98	1484	62	38	—	—	—	1245	54	46	—	—	—	1047	48	52	—	—	—	880	44	56	—	—	—
		97	—	—	—	—	—	—	1265	54	33	13	—	—	1077	48	31	21	—	—	920	43	29	28	—	—
	>5.0 ≤6.0	87	1204	—	61	39	—	—	996	—	51	49	—	—	829	—	44	56	—	—	693	—	40	60	—	—
		98	1444	60	40	—	—	—	1186	53	47	—	—	—	969	45	55	—	—	—	803	42	58	—	—	—
		97	—	—	—	—	—	—	1206	51	33	16	—	—	1009	46	30	24	—	—	843	41	28	31	—	—
95	≥1.6 ≤2.7	87	1084	—	76	24	—	—	974	—	65	35	—	—	875	—	58	42	—	—	786	—	50	50	—	—
		98	1314	74	26	—	—	—	1174	66	34	—	—	—	1045	60	40	—	—	—	936	55	45	—	—	—

表 B. 1（续）

d_p mm	S m	杆柱代号	各种杆柱所占比例																							
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$						$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$						$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$						$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$					
			$L_{\max}$ m	抽油杆直径 mm					$L_{\max}$ m	抽油杆直径 mm					$L_{\max}$ m	抽油杆直径 mm					$L_{\max}$ m	抽油杆直径 mm				
				29	25	22	19	16		29	25	22	19	16		29	25	22	19	16		29	25	22	19	16
95	≥1.6 ≤2.7	97	—	—	—	—	—	—	—	—	—	—	—	—	1055	59	33	8	—	—	956	55	30	15	—	—
	>2.7 ≤3.3	87	1064	—	73	27	—	—	945	—	63	37	—	—	836	—	55	45	—	—	747	—	53	47	—	—
		98	1294	73	27	—	—	—	1135	64	36	—	—	—	996	57	43	—	—	—	877	52	48	—	—	—
		97	—	—	—	—	—	—	—	—	—	—	—	—	1016	57	33	10	—	—	897	51	31	18	—	—
	>3.3 ≤4.2	87	1044	—	70	30	—	—	915	—	61	39	—	—	797	—	54	46	—	—	698	—	46	54	—	—
		98	1274	72	28	—	—	—	1095	61	39	—	—	—	937	53	47	—	—	—	818	49	51	—	—	—
		97	—	—	—	—	—	—	—	—	—	—	—	—	957	53	32	15	—	—	838	48	31	21	—	—
	>4.2 ≤5.0	87	1034	—	69	31	—	—	895	—	58	42	—	—	777	—	51	49	—	—	670	—	45	55	—	—
		98	1254	70	30	—	—	—	1065	59	41	—	—	—	907	51	49	—	—	—	780	47	53	—	—	—
		97	—	—	—	—	—	—	1065	57	35	8	—	—	927	52	32	16	—	—	800	46	30	24	—	—
	>5.0 ≤6.0	87	1014	—	66	34	—	—	856	—	54	46	—	—	729	—	48	52	—	—	623	—	43	57	—	—
		98	1224	67	33	—	—	—	1016	56	44	—	—	—	849	48	52	—	—	—	713	44	56	—	—	—
		97	—	—	—	—	—	—	1036	57	33	10	—	—	869	48	32	20	—	—	723	38	33	29	—	—

注 1：抽油杆柱组合设计表（表 B. 1）在编制计算过程中，其有关参数选值如下：

$\mu_c = 1\text{mPa} \cdot \text{s}$；$\rho_{wL} = 950\ \text{kg/m}^3$；$\delta = 0.1\ \text{mm}$；$n_k = 2$ 个；$D_{ps} = 300\ \text{m}$；$p_o = 1\ \text{MPa}$；$v = 4968\ \text{m/s}$；$E = 2.058 \times 10^{11}\ \text{Pa}$；$T = 794\ \text{MPa}$；$C = 0.85$；$SF = 0.9$。

注 2：抽油杆柱组合设计表（表 B. 1）在编制过程中，假设油管柱已锚定。

附　录　C

（资料性附录）

抽油杆柱组合设计方法与步骤

C.1　抽油杆柱下部加重杆设计方法与步骤

C.1.1　由已知 D_b，S，n 三参数并以 D_b 作为 L_{max}，在附录 B 表 B.1 中查出合适的抽油杆柱组合形式及各级抽油杆柱所占比例。

C.1.2　泵筒与柱塞间摩擦载荷按式（C.1）计算：

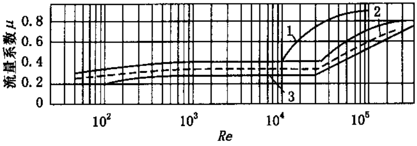
$$F_2 = 0.94(d_p/\delta) - 140 \qquad \text{(C.1)}$$

C.1.3　液体通过排出阀的水力阻力所产生的对柱塞底部的向上推力计算如下。

C.1.3.1　雷诺数按式（C.2）计算：

$$Re = 52.63nS\rho_{wL}d_p^2/(d_o\mu_o) \qquad \text{(C.2)}$$

C.1.3.2　流量系数计算：流量系数 μ 可由图 C.1 中的 $\mu = f$（Re）实验曲线确定，亦可按式（C.3）或式（C.4）计算求得。



1—单钢球箱式；
2—单钢球标准型；
3—双球。

图 C.1　实验曲线图

$$\mu = 0.28（当\ Re \leqslant 3 \times 10^4\ 时） \qquad \text{(C.3)}$$

$$\mu = 0.37 - \ln Re - 1.38（当\ Re > 3 \times 10^4\ 时） \qquad \text{(C.4)}$$

C.1.3.3　液体通过排出阀的水力阻力所产生对柱塞底部的向上推力按式（C.5）计算：

$$F_5 = \frac{1.5n_k}{729\mu^2} \times \frac{A_p^3(1 - A_o/A_p)}{A_o^2} \times (Sn)^2\rho_{wL} \qquad \text{(C.5)}$$

其中：

$$A_p = (\pi/4)d_p^2$$

$$A_o = (\pi/4)d_o^2$$

C.1.4　作用于抽油杆柱底部液体上浮力按式（C.6）计算：

$$P_{br} = A_{r1}D_p\rho_{wL}g \qquad \text{(C.6)}$$

C.1.5　下行程时抽油杆柱底部所受的总下行阻力按式（C.7）计算：

$$P_w = F_2 + F_{br} + F_5 \qquad \text{(C.7)}$$

C.1.6　需配加重杆长度按式（C.8）计算：

$$L_{sb} = \frac{P_w}{A_w\rho_r g} \qquad \text{(C.8)}$$

C.1.7　考虑井斜角的变化，加重杆的长度可按照式（C.9）计算：

$$L_{\mathrm{sb}}=\frac{0.98E'\gamma_{\mathrm{L}}D_{\mathrm{p}}}{W_j\cos\alpha_{\mathrm{v}}(1-0.128\gamma_{\mathrm{t}})}\quad\cdots\cdots\quad(\mathrm{C}.9)$$

其中加重杆系数 E' 可按表 C.1 查得。

表 C.1 加重杆系数

泵 径 mm	加重杆系数 cm^3	泵 径 mm	加重杆系数 cm^3
28	1.94	57	3.55
32	1.94	64	3.87
38	2.58	70	4.52
44	2.90	83	7.23
50	3.23	95	9.03

C.2 加重杆上部抽油杆柱近似等强度组合设计方法与步骤

C.2.1 各级抽油杆柱长度计算。

根据 C.1.1 选定的抽油杆柱组合形式及各级抽油杆柱所占比例，各级抽油杆柱长度 L_{ri} 按式（C.10）计算：

$$L_{ri}=(D_{\mathrm{p}}-L_{\mathrm{sb}})\Delta i\quad\cdots\cdots\quad(\mathrm{C}.10)$$

C.2.2 抽油杆柱长度加权平均截面积按式（C.11）计算：

$$A_{\mathrm{r}}=D_{\mathrm{p}}\Big/\left(\sum_{i=1}^{M}\frac{L_{ri}}{A_{ri}}+\frac{L_{\mathrm{sb}}}{A_{\mathrm{w}}}\right)\quad\cdots\cdots\quad(\mathrm{C}.11)$$

C.2.3 油管柱长度的加权平均横截面积按式（C.12）计算：

$$A_{\mathrm{t}}=D_{\mathrm{p}}\Big/\sum_{j=1}^{Z}\frac{L_j}{A_{tj}}\quad\cdots\cdots\quad(\mathrm{C}.12)$$

C.2.4 抽油杆柱在液体中的重力按式（C.13）计算：

$$W_{\mathrm{rf}}=\frac{\rho_{\mathrm{r}}-\rho_{\mathrm{wL}}}{\rho_{\mathrm{r}}}\left(\sum_{i=1}^{M}L_{ri}q_i+P_{\mathrm{w}}\right)\quad\cdots\cdots\quad(\mathrm{C}.13)$$

C.2.5 作用在抽油泵柱塞上的液体载荷按式（C.14）计算：

$$P_{\mathrm{L}}=[(D_{\mathrm{p}}-D_{\mathrm{ps}})\rho_{\mathrm{wL}}g+P_{\mathrm{o}}]A_{\mathrm{p}}\quad\cdots\cdots\quad(\mathrm{C}.14)$$

C.2.6 抽油机从上冲程开始到液柱载荷完毕时（初变形期）悬点位移按式（C.15）或式（C.16）计算：

$$\lambda=\frac{P_LD_p}{EA_{\mathrm{r}}}\quad\text{（油管锚定）}\quad\cdots\cdots\quad(\mathrm{C}.15)$$

$$\lambda=\frac{P_{\mathrm{L}}D_{\mathrm{p}}}{E}\left(\frac{1}{A_{\mathrm{r}}}+\frac{1}{A_{\mathrm{t}}}\right)\quad\text{（油管未锚定）}\quad\cdots\cdots\quad(\mathrm{C}.16)$$

C.2.7 抽油机从上冲程开始到液柱载荷完毕时（初变形期）曲柄转角按式（C.17）计算：

$$\phi_{\mathrm{c}}=\arccos(1-2\lambda/S)\quad\cdots\cdots\quad(\mathrm{C}.17)$$

C.2.8 变形分布系数按式（C.18）或式（C.19）计算：

$$\Psi=A_{\mathrm{t}}/(A_{\mathrm{r}}+A_{\mathrm{t}})\quad\text{（油管未锚定）}\quad\cdots\cdots\quad(\mathrm{C}.18)$$

$$\Psi=1\quad\text{（油管锚定）}\quad\cdots\cdots\quad(\mathrm{C}.19)$$

C.2.9 悬点最大、最小载荷按式（C.20）、式（C.21）计算：

$$P_{\mathrm{mh,max}}=W_{\mathrm{rf}}+P_{\mathrm{L}}+\frac{EA_{\mathrm{r}}}{v}\cdot\frac{\pi Sn}{60}\left[\sin\left(\phi_{\mathrm{c}}+\frac{\pi nD_{\mathrm{p}}}{30v}\right)-(1-\psi)\sin\phi_{\mathrm{c}}\right]\quad\cdots\cdots\quad(\mathrm{C}.20)$$

$$P_{\mathrm{mh,min}} = W_{\mathrm{rf}} - C \cdot \frac{EA_{\mathrm{r}}}{v} \cdot \frac{\pi Sn}{60}\left[\sin\left(\phi_{\mathrm{c}} + \frac{\pi n D_{\mathrm{p}}}{30v}\right) - (1-\psi)\sin\phi_{\mathrm{c}}\right] \tag{C.21}$$

C.2.10 校核疲劳强度按式（C.22）计算：

$$\frac{P_{\mathrm{mh,max}}}{A_{\mathrm{rJ}}} \leqslant \left(\frac{T}{4} + 0.5625\,\frac{P_{\mathrm{mh,min}}}{A_{\mathrm{rJ}}}\right) SF \tag{C.22}$$

如果按式（C.22）校核不适应，则重新选择抽油杆柱组合型式或更换高强度抽油杆，再重复按上述抽油杆柱组合设计方法进行计算。

C.2.11 曲柄轴最大扭矩按式（C.23）计算：

$$M_{\mathrm{ca,max}} = 300S + 0.236S(P_{\mathrm{mh,max}} - P_{\mathrm{mh,min}}) \tag{C.23}$$

C.3 加重杆上部抽油杆柱等强度组合设计方法与步骤

C.3.1 用迭代法从加重杆顶端抽油杆开始向上，每增加一个抽油杆长度 ΔL，进行一次 C.3.2～C.3.10 计算。

C.3.2 校核点以下抽油杆柱长度加权平均截面积按式（C.24）计算：

$$A_{\mathrm{sJ}} = L_{\mathrm{J}} \Big/ \left(\sum_{i=1}^{M} \frac{L_i}{A_{ri}} + \frac{L_{\mathrm{sb}}}{A_{\mathrm{w}}}\right) \tag{C.24}$$

其中：

$$L_{\mathrm{J}} = \sum_{i=1}^{M} L_{ri} + L_{\mathrm{sb}}$$

C.3.3 油管柱金属部分长度的加权平均截面积按式（C.25）计算：

$$A_{\mathrm{t}} = D_{\mathrm{p}} \Big/ \sum_{j=1}^{Z} \frac{L_j}{A_{tj}} \tag{C.25}$$

C.3.4 校核点以下抽油杆柱在液体中的重力按式（C.26）计算：

$$W_{\mathrm{rfJ}} = [(\rho_{\mathrm{r}} - \rho_{\mathrm{wL}})/\rho_{\mathrm{r}}] \cdot \left(\sum_{i=1}^{M} L_{ri} q_i + P_{\mathrm{w}}\right) \tag{C.26}$$

C.3.5 作用在抽油泵柱塞上的液体载荷按式（C.14）计算。

C.3.6 抽油机从上冲程开始到液体载荷加载完毕时（初变形期）校核点位移按式（C.27）或式（C.28）计算：

$$\lambda_{\mathrm{J}} = \frac{P_{\mathrm{L}} L_{\mathrm{J}}}{EA_{\mathrm{sJ}}} \quad \text{（油管锚定）} \tag{C.27}$$

$$\lambda_{\mathrm{J}} = \frac{P_{\mathrm{L}}}{E}\left(\frac{L_{\mathrm{J}}}{A_{\mathrm{sJ}}} + \frac{D_{\mathrm{p}}}{A_{\mathrm{t}}}\right) \quad \text{（油管未锚定）} \tag{C.28}$$

C.3.7 抽油机从上冲程开始到液体载荷加载完毕时曲柄转角按式（C.29）计算：

$$\phi_{\mathrm{cJ}} = \arccos(1 - 2\lambda_{\mathrm{J}}/S) \tag{C.29}$$

C.3.8 变形分布系数按式（C.30）或式（C.31）计算：

$$\psi_{\mathrm{J}} = A_{\mathrm{t}}/(A_{\mathrm{sJ}} + A_{\mathrm{t}}) \quad \text{（油管未锚定）} \tag{C.30}$$

$$\psi_{\mathrm{J}} = 1 \quad \text{（油管锚定）} \tag{C.31}$$

C.3.9 校核点最大、最小载荷按式（C.32）、式（C.33）计算：

$$P_{\mathrm{mh,maxJ}} = W_{\mathrm{rfJ}} + P_{\mathrm{L}} + \frac{EA_{\mathrm{sJ}}}{v} \cdot \frac{L_{\mathrm{J}}}{D_{\mathrm{p}}} \cdot \frac{\pi Sn}{60}\left[\sin\left(\phi_{\mathrm{cJ}} + \frac{\pi n L_{\mathrm{J}}}{30v}\right) - (1-\psi_{\mathrm{J}})\sin\phi_{\mathrm{cJ}}\right] \tag{C.32}$$

$$P_{\mathrm{mh,minJ}} = W_{\mathrm{rfJ}} - C \cdot \frac{EA_{\mathrm{sJ}}}{v} \cdot \frac{L_{\mathrm{J}}}{D_{\mathrm{p}}} \cdot \frac{\pi Sn}{60}\left[\sin\left(\phi_{\mathrm{cJ}} + \frac{\pi n L_{\mathrm{J}}}{30v}\right) - (1-\psi_{\mathrm{J}})\sin\phi_{\mathrm{cJ}}\right] \tag{C.33}$$

C.3.10 疲劳强度按式（C.22）计算校核。

C.3.11 如果按式（C.22）校核不适应，增加抽油杆柱直径一个等级，继续重复 C.3.2～C.3.10 计算。

C.3.12 当抽油杆直径增加到大于选定的抽油杆柱组合形式中最大直径的抽油杆柱时，得出该种抽

油杆柱组合形式的极限下泵深度值 $L_{\max}$。

C.3.13 比较 D_p 和 $L_{\max}$。

当 $D_p > L_{\max}$ 时，重新选择抽油杆柱组合型式或更换更高强度抽油杆；

当 $D_p < L_{\max}$ 时，重新选择抽油杆柱组合型式或更换更低强度抽油杆，也可调整 SF 值（减小 SF 值），继续重复 C.3.1～C.3.11 计算，直到 $D_p = L_{\max}$ 为止，此时计算出的抽油杆柱组合形式即为适应油井实际工况条件的等强度组合抽油杆柱。

C.3.14 曲柄轴最大扭矩按式（C.23）计算。

C.4 斜井加重杆上部抽油杆柱组合设计方法与步骤

设井眼轴线相邻两井斜测点为一段，整个井眼轴线长度是由许多曲率半径不等的圆弧曲线组成（见图 C.2），井眼轴线上任一段在垂直面上投影曲率半径为 R_i，在水平面投影的曲率半径为 r_i。以抽油泵柱塞上端面对应井斜测点为起始点，依次为 $i = 0, 1, 2, 3, \cdots, n$。通过逐段计算每段上端载荷 P_i，并将它作为计算下一段公式中的 P_{i-1}，这样直到算出悬点的最大载荷和最小载荷。抽油杆若为多级组合，则验算每级杆柱上端的最大应力 $\sigma_{r,\max}$ 和最小应力 $\sigma_{r,\min}$。调整各级杆柱长度达到 $\sigma_{r,\max} < \sigma_{rp,\max}$。

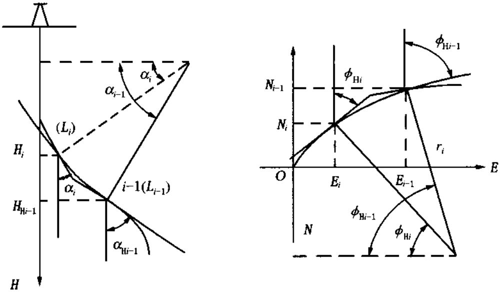


图 C.2 井眼轨迹在垂直面上投影和水平面上投影

C.4.1 i 井段对应抽油杆的单位长度对油管内壁的挤压力按式（C.34）计算：

$$N_i = \sqrt{\left[p_{i-1} \cdot \frac{1}{R_i} - (1 \pm m_a) W_{ri} \sin\alpha_{vi}\right]^2 + \left(p_{i-1} \cdot \frac{1}{r_i} \sin^2\alpha_{vi}\right)^2} \quad \cdots\cdots\cdots\cdots\cdots \text{(C.34)}$$

其中：

$$\frac{1}{R_i} = \frac{\alpha_{i-1} - \alpha_i}{57.3 \mid \Delta L_i \mid}$$

$$\frac{1}{r_i} = \frac{\phi_{Hi-1} - \phi_{Hi}}{57.3 \mid \Delta L_i \mid \sin\alpha_{vi}}$$

当抽油杆柱上行时，式中“±”取“+”，下行时取“－”。

C.4.2 i 井段对应抽油杆与油管之间的摩擦负荷按式（C.35）计算：

$$F_{1i} = f N_i \mid \Delta L_i \mid \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(C.35)}$$

其中：

$$\Delta L_i = L_i - L_{i-1}$$

C.4.3 杆柱下行时 i 井段的抽油杆与液体的摩擦载荷按式（C.36）计算：

$$p_{Lri} = 3 \times 10^{-4} S n \mu_o \mid \Delta L_i \mid \left[\frac{K_{tr}^2 - 1}{(K_{tr}^2 + 1)\ln K_{tr} - (K_{tr}^2 - 1)}\right] \quad \cdots\cdots\cdots\cdots\cdots\cdots \text{(C.36)}$$

其中：

$$K_{ti} = D_{ti}/d_{ri}$$

C.4.4 上行时 i 井段抽油杆与液体的摩擦载荷按式（C.37）计算：

$$p_{Lti} = \frac{p_{Lri}}{1.3} \quad \cdots\cdots (C.37)$$

C.4.5 抽油泵泵筒与柱塞之间的摩擦载荷按式（C.1）计算。

C.4.6 作用在抽油泵活塞上的液柱载荷按式（C.14）计算。

C.4.7 i 井段抽油杆上端最大、最小载荷分别按式（C.38）、式（C.39）计算：

$$P_{mh,max} = P_{ui-1} + (1+m_a)\xi W_{ri}\cos\alpha_{vi} \mid \Delta L_i \mid + \xi P_w + P_{ti} + P_{Lti} \quad \cdots\cdots (C.38)$$

$$P_{mh,min} = P_{di-1} + (1+m_a)\xi W_{ri}\cos\alpha_{vi} \mid \Delta L_i \mid + \xi P_w - P_{wi} - P_{Lti} \quad \cdots\cdots (C.39)$$

其中：

$$m_a = \frac{Sn^2}{1790}$$

C.4.8 疲劳强度按式（C.22）计算校核。如果按式（C.22）校核不适应，则重新选择抽油杆柱组合形式或更换更高强度抽油杆，再重复按上述抽油杆柱组合设计方法进行计算。

C.4.9 曲柄轴最大扭矩按式（C.23）计算。

C.5 抽油杆柱组合设计方法示例

已知抽油泵公称直径 $d_p = 44$mm，泵隙为Ⅰ级（$\delta = 0.035$mm），有两个排出阀，抽油泵下入深度 $D_p = 1800$m，动液面深度 1400m，井口回压 0.7MPa，采出液体中含少量盐，液体动力粘度 10mPa·s，密度 850kg/m^3，生产参数：$S = 6$m，$n = 4\text{min}^{-1}$；油管柱未锚定，需设计抽油杆柱。

C.5.1 初定抽油杆强度级别：因采出液体中含少量盐，载荷较重，试选用 D 级抽油杆，其最低抗拉强度 $T = 793$MPa，取 $SF = 0.9$。

C.5.2 初选抽油杆柱组合型式：由已知 $d_p = 44$mm，$S = 6$m，$n = 4\text{min}^{-1}$，$D_p = 1800$m。查表 B.1，选择代号为 65 的抽油杆柱较为合适，其最大下泵深度 $L_{max} = 1843$m，杆柱由 58％的 19mm 抽油杆、42％的 16mm 抽油杆二级组成。

C.5.3 抽油泵泵筒与柱塞之间的摩擦载荷计算［按式（C.1）］：

$$F_2 = 0.94(d_p/\delta) - 140 = 1041(\text{N})$$

C.5.4 雷诺数计算［按式（C.2）］：

$$Re = 52.63nS\rho_{wL}d_p^2/(d_o\mu_o) = 9448$$

C.5.5 流量系数计算：因为 $Re = 9448 < 3 \times 10^4$，根据式（C.3）知，$\mu = 0.28$。

C.5.6 液体通过排出阀的水力阻力所产生的对柱塞底部向上推力计算［按式（C.5）］：

$$F_5 = \frac{1.5n_k}{729\mu^2} \times \frac{A_p^3(1 - A_o/A_p)}{A_o^2} \times (Sn)^2\rho_{wL} = 780(\text{N})$$

C.5.7 作用于抽油杆底部液体浮力计算［按式（C.6）］：

$$F_{br} = A_{r1}D_p\rho_{wL}g = 3014(\text{N})$$

C.5.8 下行程时抽油杆柱底部所受的总下行阻力计算［按式（C.7）］：

$$P_w = F_2 + F_{br} + F_5 = 4835(\text{N})$$

C.5.9 需配加重杆长度计算［按式（C.8）］：设选用加重杆的直径为 38mm，则：

$$L_{sb} = P_w/(A_w\rho_r g) = 44(\text{m})$$

C.5.10 各级抽油杆长度计算［按式（C.10）］：

16mm 抽油杆柱 $L_{r1} =$（$D_p - L_{sb}$）$\Delta i =$（1800 − 44）×41％ = 738（m）

19mm 抽油杆柱 $L_{r2} = 1800 - 44 - 738 = 1018$（m）

组合结果：38mm×44 + 19mm×1018 + 16mm×738

C. 5. 11 抽油杆柱加权平均截面积计算［按式（C. 11）］：

$$A_r = D_p / \left(\sum_{i=1}^{M} \frac{L_{ri}}{A_{ri}} + \frac{L_{sb}}{A_w} \right) = 0.000246(\mathrm{m}^2)$$

C. 5. 12 油管柱加权平均截面积计算［按式（C. 12）］：根据 C. 10 计算出的各级抽油杆长度，选择油管柱为：73mm×1800m，由此得：

$$A_t = D_p / \sum_{j=1}^{Z} \frac{L_j}{A_{tj}} = 0.001165(\mathrm{m}^2)$$

C. 5. 13 抽油杆柱在液体中的重力计算［按式（C. 13）］：

$$W_{rf} = \frac{\rho_r - \rho_{wL}}{\rho_r} \left(\sum_{i=1}^{M} L_{ri} q_i + P_w \right) = 37502(\mathrm{N})$$

C. 5. 14 液体载荷计算［按式（C. 14）］：

$$P_L = [(D_p - D_{ps}) P_{wL} g + P_o] A_p = 16370(\mathrm{N})$$

C. 5. 15 计算初变形期末悬点位移：由于油管柱未锚定，故按式（C. 16）计算：

$$\lambda = \frac{P_L D_p}{E} \left(\frac{1}{A_r} + \frac{1}{A_t} \right) = 0.38(\mathrm{m})$$

C. 5. 16 初变形期曲柄转角计算［按式（C. 17）］：

$$\phi_c = \arccos(1 - 2\lambda / S) = 0.51(\mathrm{rad})$$

C. 5. 17 计算变形分布系数：由于油管柱未锚定，故按式（C. 18）计算：

$$\psi = A_t / (A_r + A_t) = 0.825$$

C. 5. 18 悬点最大、最小载荷计算［按式（C. 20）、式（C. 21）］：

$$P_{mh,max} = W_{rf} + P_L + \frac{EA_r}{v} \cdot \frac{\pi S n}{60} \left[\sin\left(\phi_c + \frac{\pi n D_p}{30 v} \right) - (1 - \psi) \sin\phi_c \right] = 60683(\mathrm{N})$$

$$P_{mh,min} = W_{rf} - C \frac{EA_r}{v} \cdot \frac{\pi S n}{60} \left[\sin\left(\phi_c + \frac{\pi n D_p}{30 v} \right) - (1 - \psi) \sin\phi_c \right] = 30690(\mathrm{N})$$

C. 5. 19 校核疲劳强度［按式（C. 22）］：

其中：

$$\frac{P_{mh,max}}{A_{rJ}} = 214(\mathrm{MPa})$$

$$\left(\frac{T}{4} + 0.5625 \frac{P_{mh,min}}{A_{rJ}} \right) SF = 233(\mathrm{MPa})$$

则：

$$\frac{P_{mh,max}}{A_{rJ}} < \left(\frac{T}{4} + 0.5625 \frac{P_{mh,min}}{A_{rJ}} \right) SF$$

故抽油杆柱强度足够。

附　录　D

（资料性附录）

有杆泵抽油作业施工设计书

D.1　施工设计书纸张要求

设计书纸张的尺寸为190mm×265mm，即为A4。

D.2　施工设计书格式

施工设计书格式见表D.1。

表D.1　________井作业施工设计书

施工目的							
油井基础数据	套管规格及深度	mm×　m	套管壁厚	mm	生产动态数据	产液	t/d
	射孔井段	m	套补距	m		产油	t/d
	油层中部深度	m	人工井底	m		含水	%
	抽油机型号		造斜点深度	m		流压	MPa
	总水平位移	m	全角变化率	(°) /30m		静压	MPa
	最大井斜	井段，m	最大井斜角	(°)		测静压时间	年　月　日
井况及存在问题							
原井管柱							
设计管柱示意图					施工要求及注意事项		
层位	管柱	名称	深度 m	规格 m			
设计单位		设计人		初审			
审核		审批人		设计时间			

D.3　施工设计书填写要求

D.3.1　施工目的栏填写要求

在施工目的栏填写本次施工目的。如有非本施工目的所含的其他施工内容在此次施工时合并进行，则应在本次施工目的后自左至右顺序填写，每项之间用逗点隔开。如项目太多一行写不下，则另起一行，但单项不能跨行。

D.3.2　生产动态数据及原井管柱情况栏填写要求

生产动态数据及原井管柱情况应在油井调查的基础上填写。生产动态数据是提供给作业队考虑有关压井（或不压井起下控制）、洗井等问题。原井管柱情况应提供上次作业时间和井内杆柱、管柱情况及与此次施工相关的管柱结构和井下工具情况等，作为作业部门备料和安排此次施工工作步骤的依据。

D.3.3　设计管柱示意图栏填写要求

对无堵水、配产、防砂等控制某些层位的抽油井，层位栏目可不必标画，否则应在管柱图的对应深度处画出油层示意图并标明层位代号及必要的深度数据。在管柱图栏目中，按所安排的各井下工具的相对位置画出示意图，并向右作平行引出线至规格栏右边线。油管和抽油杆可在本级的任一位置拉引出线；泵在固定阀端拉引出线；其他井下工具均在底部拉引出线。封隔器标明其胶筒上界深度。规格栏数据采用公称尺寸。深度数据需严格限制的可根据需要标出足够的精确度，在没有严格限制时应将个位数置零，以示施工部门不必为某一数据特配短节。

D.3.4　井况及存在问题栏填写要求

该栏填写井身状况及需施工部门注意的油井问题，诸如告知套管变形性质和变点深度，告知井下落物内容及鱼顶深度等。

D.3.5　施工要求及注意事项栏填写要求

该栏填写施工安排有关要求，诸如要求对好的防冲距数值、抽油杆倒序等。

D.3.6　油井基础数据栏填写要求

如果是斜井，造斜点深度、总水平位移、全角变化率、最大井斜及最大井斜角等数据要求填写；直井不必填写。

附　录　E
（资料性附录）
有杆泵常规抽油作业施工总结

E.1　施工总结幅面尺寸

印制施工总结单页尺寸为190mm×265mm，即为A4。

E.2　施工总结的格式

施工总结的格式见表E.1～表E.6。

表E.1　________井作业施工总结

施工目的：				
基本数据	套管规格及深度	mm×　m	人工井底	m
	射孔井段	m	油层中部深度	m
	套补距	m	四通高	m
施工日期：　年　月　日至　年　月　日				
下井管柱示意图	下井管柱主要数据			
	泵径	mm	泵深	m
	泵制造厂		丝堵深度	m
	光杆规格及长度		mm×　m	
	油管规格及根数		mm×　根	
	抽油杆规格、根数及长度		mm×　根×　m	

施工单位：　　　　编写人：　　　　审核人：

表E.2　________井原井管柱图及原井况分析

原井管柱图：	原井况分析：

施工单位：　　　　编写人：　　　　审核人：

表 E.3 __________井施工工序说明

工序	完成时间	主要数据和内容

施工单位：　　　　编写人：　　　　审核人：

表 E.4 __________井问题分析

问题分析：

施工单位：　　　　编写人：　　　　审核人：

表 E.5 ________井油管记录

下井日期：　　年　月　日

编号	长　度 m	累积长度 m	编号	长　度 m	累积长度 m	编号	长　度 m	累积长度 m	编号	长　度 m	累积长度 m
								规范		
								类型		
								内径规	直径	
									长度	
								套补距		
								四通高		
								油管挂		
								泵	长度	
									直径	
									深度	
								累计长度		
								深度		
								工作筒		
									深度	
									内径	
								测量人		
								计算人		
								审核人		

施工单位：　　　　　　　　　　　　　　　　　　　　　　队长：

表 E.6 ____________ 井抽油杆记录

下井日期：　　年　月　日

编号	长度 m	累积长度 m	编号	长度 m	累积长度 m	编号	长度 m	累积长度 m	编号	长度 m	累积长度 m
								光杆规范		
								一级杆		
								二级杆		
								三级杆		
								活塞		
									长度	
									直径	
								累计长度		
								测量人		
								计算人		
								审核人		

施工单位：　　　　　　　　　　　　　　　　队长：

E.3 施工总结填写要求

E.3.1 原井况分析栏填写要求

在原井况分析栏填写该井本次施工前井下管柱情况，以及井筒情况。例如，井内是否有丢手管柱，是否有特殊工具，是否有套变等。

E.3.2 问题分析栏填写要求

在问题分析栏填写本次施工时出现的问题。杆管磨损情况、起出的井下工具的描述、井筒状况描述以及施工中出现问题所采取的措施。

E 14
Record No: 16466—2005

SY

The People's Republic of China
Standard of Petroleum and Natural Gas Industry

SY/T 5873—2005

Replace SY/T 5873.1—1993, SY/T 5873.2—1994, SY/T 5873.3—1993,
SY/T 5873.4—1993, SY/T 5903—1993, SY/T 5905—1993

Recommended practices for design and execution of sucker rod pumping system

Issued Date: 07—26—2005 **Implementation Date: 11—01—2005**

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Contents

Foreword

This Standard is an integrated revision and replace of such six standards as SY/T 5873.1—1993 *Practice for sucker rod pumping job—Part 1: Conventional pumping*, SY/T 5873.2—1994 *Practice for sucker rod pumping job—Part 2: Deep pumping*, SY/T 5873.3—1993 *Practice for sucker rod pumping job—Part 3: For deviated-well*, SY/T 5873.4—1993 *Practice for sucker rod pumping job—Part 4: Pumping with large-sized pump*, SY/T 5903—1993 *Design method for tapered sucker rod string* and SY/T 5905—1993 *Practice for sizing of beam pumping unit*. Its main modifications to the previous standards go as follows:

- —The structure, elements and formulation of this standard is revised in compliance with GB/T 1.1—2000 *Directives for standardization—Part 1: Rules for the structure and drafting of standards*.
- —The basic parameter table and chart selecting of the beam pumping unit is upgraded in accordance with SY/T 5044—2003 *Beam pumping unit*. The size of 18－6－146 is added in the table and chart, making the sizes of the beam pumping unit increasing from 27 to 28.
- —The design method of tapered sucker rod string for deviated well is added. The symbol used to represent a tapered sucker rod string is modified with the symbol of its uppermost stage before that of its bottommost stage.
- —The values of tensile strength of sucker rod is upgraded in accordance with SY/T 5029—2003 *Sucker rod*.
- —HSE stipulations regarding the downhole operation is added.
- —The schematic layout of the tubing string is redrawed in compliance with SY/T 5952.
- —Some regulations with regard to job execution make direct reference to standards in current use.
- —Annexes A, B, C, D and E are informative.

This standard is proposed by and under the jurisdiction of Professional Standard Committee of Oil and Gas Production.

The drafting departments: Oil Production Research Institute of SINOPEC Shengli Oilfield Co. Ltd. Oil Exploitation Department of PetroChina Daqing Oilfield Company Ltd.

This standard is drafted by Feng Yongquan, Zhang Junqing, Jiang Dong, Luo Yan, Chu Yongming, Dong Degui, Chen Xianjin, Liu Changfu.

The previously published version of the standard replaced by this standard:

- ——SY/T 5873.1—1993;
- ——SY/T 5873.2—1994;
- ——SY/T 5873.3—1993;
- ——SY/T 5873.4—1993;
- ——SY/T 5903—1993;
- ——SY/T 5905—1993.

This standard is published in both Chinese and English. In the event of any discrepancy between the texts, the Chinese version shall prevail.

Recommended practices for design and execution of sucker rod pumping system

1 Scope

The Standard specifies the practice for selection and installation of the beam pumping unit, the practice for subsurface pump selection, the practice for grade selection and design of tapered sucker rod string, configuration design of sucker rod string and tubing string, and job execution. The standard is applicable to design and execution of sucker rod pumping system.

2 Normative references

The following normative documents contain provisions which, through reference in this standard, constitute provisions of this standard. For dated references, subsequent amendments to, or revisions of, any of these publications (exclude errata) do not apply. However, parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

GB/T 18607—2001 *Specifications for sucker rod pump and its components*

SY/T 0408—2000 *Specifications for installation and acceptance of pumping unit*

SY/T 5029—2003 *Sucker rod*

SY/T 5044—2003 *Beam pumping unit*

SY/T 5059 *Tubing pump with combined barrel*

SY/T 5587.3—2004 *Operating regulations for conventional well workover operations—Part 3: Killing and induced flowing*

SY/T 5587.5—2004 *Operating regulations for conventional well workover operations—Part 5: Well bore preparation for downhole operations*

SY/T 6361—1998 *Guide for framework of management of HSE for producing and injecting well site*

SY/T 6362—1998 *Guide for framework of management of HSE for downhole operations of petroleum industry*

3 Symbol

3.1 As shown in Table 1, the symbol used to represent a tapered sucker rod string is made up of symbols of its uppermost and bottommost stages with the former before the latter. For example, the symbol of the sucker rod string composed of sucker rods with diameters of 19mm, 16mm and 13mm is 64.

3.2 Symbols of physical quantities are shown in Table 2.

Table 1 Symbol of sucker rods

Sucker rod symbol	9	8	7	6	5	4
Sucker rod diameter mm	29	25	22	19	16	13

Table 2 Symbols of physical quantities

No.	Symbol	Description	Unit
1	$[\Delta\sigma]$	Allowable stress range	MPa
2	$[M_{max}]$	Rated torque	N • m

Table 2 (continued)

No.	Symbol	Description	Unit
3	$[P_{\max}]$	Polished rod load rating	N
4	$\sum\alpha$	Sum of deviation angles at ends of hole section ΔL	(°)
5	Δi	Percentage of stage i of tapered sucker rod string	1
6	ΔL	Hole section length at the pump-setting depth	m
7	ΔL_i	Sucker rod length of hole section i	m
8	$\Delta\alpha$	Difference of deviation angles at ends of hole section ΔL	(°)
9	$\Delta\phi_{\mathrm{H}}$	Difference of azimuths at ends of hole section ΔL	(°)
10	a	Constant, $a = 0.25$	1
11	A_{o}	Inner cross-section area of the traveling valve seat	m^2
12	A_{p}	Cross-section area of pump plunger	m^2
13	A_{r}	Length-weighted average cross-section area of sucker rod string	m^2
14	$A_{\mathrm{r}i}$	Cross-section area of stage i of sucker rod string	m^2
15	A_{rJ}	Cross-section area of the sucker rod at the check point	m^2
16	A_{r1}	Cross section area of the bottommost stage of sucker rod string	m^2
17	A_{sJ}	Length-weighted average cross-section area of sucker rod string below the check point	m^2
18	A_{t}	Length-weighted average cross-section area of tubing string	m^2
19	$A_{\mathrm{t}j}$	Cross-section area of stage j of tubing string	m^2
20	A_{w}	Cross-section area of sinker bar	m^2
21	b	Constant, $b = 0.5625$	1
22	C	Correction coefficient for downstroke dynamic load, which is dependent on geometric parameters of the pumping unit and pump fullness, generally $C = 0.85 \sim 0.9$ when fluid free of gas is pumped.	1
23	D	ID of production casing	mm
24	d_{o}	ID of traveling valve seat	m
25	D_{b}	OD of subsurface pump	mm
26	d_{p}	Nominal diameter of subsurface pump	m
27	D_{p}	True vertical pump-setting depth	m
28	D'_{p}	Measured pump-setting depth	m
29	D_{pf}	Depth to flowing fluid level in casing	m
30	D_{ps}	working submergence of sucker rod pump	m
31	$d_{\mathrm{r}i}$	Diameter of sucker rod of hole section i	m
32	$D_{\mathrm{t}i}$	ID of tubing	m

Table 2 (continued)

No.	Symbol	Description	Unit
33	E	Elastic modulus of steel	Pa
34	E'	Factor of sinker bar	cm^3
35	f	Friction factor between sucker rod and tubing, which is dependent on properties of the reservoir oil	1
36	F_2	Friction load between the barrel and the plunger of the pump	N
37	F_{3i}	Friction force between fluid column and sucker rod string at the ith hole section	N
38	F_{4i}	Friction force between fluid column and tubing string at the ith hole section	N
39	F_5	Hydraulic resistance produced by fluid flowing through the traveling valve	N
40	F_{i-1}	Load acting on the bottom end of the ith section of sucker rod string	N
41	F_s	Contact area of the anchor slip with the casing	cm^2
42	F_t	Cross-section area of tubing	m^2
43	f_w	Water cut of well fluid	1
44	g	Gravitational acceleration	m/s^2
45	H	Mid-point depth of the formation	m
46	h	Distance from the ball/seat contact point of the valve to the inner wall of the valve cage	m
47	h_j	Setting-proof spacing of mechanical anchor or packer	cm
48	h_n	Helical pitch of tubing or sucker rod at any location below the neutral point on which there is no load acting	cm
49	i	The stage sequence of the tapered sucker rod string from bottom to top, $i=1, 2, \cdots, M$	1
50	I	Inertia moment of the tubing or sucker rod with respect to its traverse centroid	cm^4
51	j	The stage sequence of the tubing string from bottom to top, $j=1, 2, \cdots, Z$	1
52	J	The first stage of the sucker rod string below the check point	1
53	k	Weightlesness coefficient	1
54	K_{sf}	Service factor Allowing for corrosion	1
55	K_{tr}	ratio of tubing ID to sucker rod diameter	1
56	l	Stage No. of tapered sucker rod string, $l=1, 2, \cdots, l-1$	1
57	L	Length of tubing above mechanical anchor or packer	m
58	L_2	Length of tubing between the neural point and the mechanical anchor	m
59	L_b	Length of subsurface pump	mm
60	L_i	Length of sucker rod string of hole section i	m
61	L_{i-1}	Length of sucker rod string of hole section $i-1$	m
62	L_j	Length of stage j of tubing string	m
63	L_J	Length of the sucker rod string below the check point	m
64	L_{max}	Ultimate pump-setting depth of sucker rod string	m

Table 2 (continued)

No.	Symbol	Description	Unit
65	L_{ri}	Length of stage *i* of tapered sucker rod string	m
66	L_{sb}	Length of sinker bar needed	m
67	m_a	Dynamic load coeffecient	m/s^2
68	$M_{ca,max}$	Peak crankshaft torque	N • m
69	n	Strokes per minute	min^{-1}
70	N_f	The number of Nylon centralizer installed on sucker rod string	1
71	N_i	Compressive force acting on the internal wall of tubing by unit length of sucker rod at hole section *i*	N/m
72	n_e	The number of anchor slip	1
73	n_k	The number of traveling valve	1
74	N_{max}	Maximum strokes per minute	min^{-1}
75	$P_{mh,max}$	Peak polished rod load	N
76	$P_{mh,min}$	Minimum polished rod load	N
77	P_{fi}	Friction force between sucker rod and tubing at the *i*th hole section	N
78	p_b	Bubble point pressure	Pa
79	P_{br}	Buoyant force acting on the bottom of the sucker rod string	N
80	P_{Jmax}	Maximum load acting on the check point of the sucker rod	N
81	P_{Jmin}	Minimum load acting on the check point of the sucker rod	N
82	P_L	Liquid load acting on the pump plunger	N
83	P_n	Compressive force acting on any cross section of the sucker rod or the tubing below the neutral point	kN
84	p_o	Wellhead back pressure	Pa
85	p_{ps}	Submersible pressure required for a pump fullness coefficient of β	Pa
86	p_s	Pressure at the pump inlet	Pa
87	p_{sc}	Pressure under standard conditions, set at 101×10^3	Pa
88	P_t	Spring force of the anchor slip after being set	kN
89	P_w	Total resistance acting on the bottom of the sucker rod string during downstroke	N
90	p_{wf}	Flowing bottom hole pressure	Pa
91	Q	Displacement of pump	m^3/d
92	q_i	Gravity force of unit length of the *i*th stage of tapered sucker rod string	N/m
93	q_L	Daily liquid production rate	t/d
94	Q_{max}	Maximum pump displacement	m^3/d
95	q_r	Average gravity force in the air per unit length of sucker rod string	N/m
96	q_s	Gravity force in the well fluid per unit length of tubing	kN

Table 2 (continued)

No.	Symbol	Description	Unit
97	R_b	Valve ball radius	m
98	Re	Reynolds number	1
99	R_{go}	Producing gas-oil ratio	1
100	R_i	Curvature radius of the projection of section i of borehole axis on a vertical plane	m
101	r_i	Curvature radius of the projection of section i of borehole axis on a horizontal plane	m
102	R_w	Curvature radius of the wellbore axis	m
103	R_{we}	Curvature radius of the wellbore axis required to avoid bending the subsurface pump	m
104	S	Length of stroke	m
105	SF	Goodman service factor, which is an empirical value dependent on well corrosive degree, handling and maintenance of the sucker rod, etc.. Generally $SF=0.7\sim0.9$, but $SF=1.0$ for wells where new sucker rods are used and where there is no corrosion present	1
106	S_{max}	Maximum length of stroke of polished rod	m
107	S_{pmax}	Maximum effective length of stroke of pump plunger	m
108	T	Tensile strength of sucker rod	Pa
109	t	Well temperature at the pump-setting depth	℃
110	v	Propagation velocity of stress wave along the sucker rod string, $v=4968$	m/s
111	W_j	Gravity force per unit length of sinker bar in the air	N/m
112	W_L	Liquid column load	N
113	W_{ra}	Gravity force of sucker rod string in the air	N
114	W_{rf}	Gravity force of sucker rod string in the well fluid	N
115	W_{rfJ}	Gravity force of sucker rod string below the check point in the well fluid	N
116	W_{ri}	Gravity force per unit length of sucker rod string of section i	N/m
117	α	Deviation angle	(°)
118	α_e	Allowable deviation angle which ensures that the sucker rod pump runs properly at the hole section where the pump is installed	(°)
119	α_i	Azimuth of the top of borehole axis of the ith hole section	(°)
120	α_{i-1}	Azimuth of the bottom of borehole axis of the ith hole section	(°)
121	α_v	Average deviation angle of the hole section where the sinker bar is instaled	(°)
122	α_{vi}	Average deviation angle of ends of hole section i	(°)
123	β	Deviation angle variation over hole section ΔL	(°)
124	γ_L	Gravity of well fluid	kN/m^3
125	γ_r	specific density of well fluid	1
126	δ	Radial clearance between the barrel and plunger of the pump	m
127	η	Pump fullness degree required	1
128	η_p	Pump efficiency	1

Table 2 (continued)

No.	Symbol	Description	Unit
129	λ	Displacement that the hanger moves from start of upstroke till the time when fluid column load fully acts on the hanger	m
130	λ_i	Incremental length of stroke caused by inertia load	m
131	λ_J	Displacement that the check point moves from start of upstroke till the time when fluid column load fully acts on the check point	m
132	μ	Flow coefficient	1
133	μ_o	Dynamic viscosity of well fluid	mPa • s
134	ξ	Buoyancy factor, $\xi = 0.872$	1
135	ρ_r	Density of steel	kg/m^3
136	ρ_{wL}	Density of well liquid	kg/m^3
137	$\sigma_{r,max}$	Maximum stress	MPa
138	$\sigma_{r,min}$	Minimum stress	MPa
139	$\sigma_{rp,max}$	Permissible maximum stress of sucker rod	MPa
140	ϕ_c	Angle that the crank rotates from start of upstroke till the time when fluid column load fully acts on the hanger	rad
141	ϕ_{cJ}	Angle that the crank rotates from start of upstroke till the time when fluid column load fully acts on the check point	rad
142	ϕ_{Hi}	Azimuth of the bottom end of borehole axis of hole section i	(°)
143	ϕ_{Hi-1}	Azimuth of the top end of borehole axis of hole section i	(°)
144	ψ	Deformation distribution coefficient	1
145	ψ_J	Deformation distribution coefficient determined by the sucker rod string and tubing string below the check point	1

4 Practice for selection and installation of beam pumping unit

4.1 Selection principles of beam pumping unit

4.1.1 With certain parameters and pump-setting depth required, a beam pumping unit is chosen such that the polished rod load $P_{mh,max}$ and maximum reducer torque $M_{ca,max}$ should follow

$$P_{mh,max} \leqslant [P_{max}] \qquad (1)$$

$$M_{ca,max} \leqslant [M_{max}] \qquad (2)$$

4.1.2 A choice of beam pumping unit should meet the requirements of the oilfield development plan for long-term exploitation.

4.1.3 A choice of beam pumping unit should be of high utilization percent in load, reducer torque and motor power during most of its lifetime.

4.1.4 An energy-saving beam pumping unit should be preferred.

4.1.5 Sizing of beam pumping unit for wells in one block should be planned as a whole, choosing, if possible, only one beam pumping unit type and size for similar wells.

4.2 Plotting of selection chart of beam pumping unit

4.2.1 The selection chart of beam pumping unit as shown in Fig. A.2～Fig. A.5 is obtained on the base of those shown in Annex A by means of calculation which follows the sizing principles stipulated in 4. 1, co-ordinates sizing of beam pumping unit and design of the whole pumping system, and integrates the limitation of sucker rod strength.

4. 2. 2 In Fig. A. 2 ~ Fig. A. 5, region Ⅰ is suitable for a pump with a displacement of less than 200m³/d, region Ⅱ for 200m³/d～400m³/d, and region Ⅲ for greater than 400m³/d.

4. 3 Selection procedure for beam pumping unit

4. 3. 1 A proper selection chart is chosen according to the length of stroke needed on the basis of well conditions, sizes of beam pumping unit available and sizing principles of beam pumping unit stipulated in 4. 1.

4. 3. 2 On the axis of abscissa and ordinate, find the points corresponding to the daily production liquid rate q_L and pump-setting depth D_p required, respectively, and from the two points, draw a horizontal line and a vertical one, respectively, whose intersection will fall in the range of use of a certain beam pumping unit size, which is the optimum one for the well.

4. 3. 3 In order for the beam pumping unit chosen above to be capable of serving as long as the well lasts, prediction should be conducted of the production performance at the last stage of the well and, if necessary, procedures 4. 3. 1 and 4. 3. 2 should be performed again.

4. 3. 4 In case it is impossible to predict the production performance at the tail period of the well, a larger beam pumping unit size should be chosen.

4. 3. 5 An example of how to size a beam pumping unit is given in A. 5 of Annex A.

4. 4 Installation of beam pumping unit

On-site assembly sequence of the beam pumping unit is basically the same as that of shop assembly. In the case of on-site installation, there are strict requirements for the installing location of its foundation so as to ensure that the hanger is in alignment with the wellhead. Please refer to its instruction for installation and the requirements of SY/T 0408—2000 for mounting of beam pumping unit.

5 Practice for subsurface pump selection

5. 1 Selection principles of subsurface pump

5. 1. 1 Pump sizing should be based on the predicted productive capacity of a well. For a well with conventional fluid properties and pump-setting depth, pump sizing should follow the principle of adopting maximum stroke length and medium pumping speed; for a heavy or deep well, pump sizing should follow the principle of adopting maximum stroke length and low pumping speed. A pump sized this way is capable of not only achieving reasonable production response but allowing for adjusting working parameters on the surface when there is a difference between practical well deliverability and that predicted after the well is put on stream.

5. 1. 2 Pump fit selection should depend on viscosity of the well fluid. For a conventional well with a fluid viscosity below 0. 1Pa • s, clearance Ⅰ may be chosen; for a well with a fluid viscosity in the range of 0. 1Pa • s～0. 43 Pa • s, clearance Ⅱ may be chosen; and for a well with a viscosity ranging from 0. 43Pa • s to 1. 10Pa • s, clearance Ⅲ may be chosen. The amount of leakage of the subsurface pump of every clearance number should not be in excess of that stipulated in SY/T 5059.

5. 1. 3 For a deep stringer, an insert pump should be preferred.

5. 1. 4 For a well with high gas-oil ratio, sand cut or viscosity, a specialized subsurface pump should be utilized; for a well where a long tailpipe is needed below the pump for a certain reason, a bridge type subsurface pump should be applied; for a long-stroke well, a pump with one-piece barrel should be used; for a slim well with high productivity, a tandem pump should be suitable; and for a deviated well, a hanging type pump with one-piece barrel should be considered.

5.2 Pump efficiency selection

5.2.1 Pump efficiency may be chosen based on those wells producing from the same reservoir.

5.2.2 Pump efficiency may be chosen based on the previous production report.

5.2.3 A pump efficiency of 60%～70% is generally recommended.

5.3 Determination of pump size

The size of a subsurface pump is given by

$$d_p = 0.0297\sqrt{\frac{q_L}{Sn\eta_p\rho_{wL}}} \qquad (3)$$

5.4 Determination of pump-setting depth

5.4.1 Vertical well

The pump-setting depth is given by

$$D_p = H - \frac{p_{wf} - p_{ps}}{\rho_{wL}g} \qquad (4)$$

where

$$p_{ps} = \frac{R_{go}p_{sc}p_b(1-f_w)(273+t)/293}{p_b(1/\beta - 1) + R_{go}p_{sc}(1-f_w)(273+t)/293}$$

5.4.2 Deviated Well

Firstly, determine the pump-setting TVD D_p and convert it into pump-setting MD D_p'. Then, if necessary, adjust the pump-setting TVD to meet the requirements of the subsurface pump for the deviation angle and curvature radius of the well bore.

5.4.2.1 When the deviation angle α at the converted pump-setting MD is less than 35°, the pump-setting TVD corresponding to the MD may be initially determined as the pump setting depth.

5.4.2.2 When the deviation angle $\alpha > 35°$, in order to ensure that the pump work stably, the deviation angle has to be checked against deviation angle allowable α_e, which is given by

$$\alpha_e = 2\left(\arccos\sqrt{\frac{h}{2R_b}} - 45\right) \qquad (5)$$

5.4.2.3 R_w, curvature radius of the section ΔL of the borehole axis at the pump-setting MD, has to be greater than R_{we}, allowable curvature radius of borehole axis to avoid bending the pump barrel, namely $R_w > R_{we}$.

R_{we}, allowable curvature radius of borehole axis to avoid bending the pump barrel, is given by

$$R_{we} = \frac{L_b^2}{8(D - D_b)} \qquad (6)$$

R_w, curvature radius of the section ΔL of borehole axis at the pump-setting TVD D_p, is given by

$$R_w = \frac{\Delta L\sqrt{2(1+\cos\beta)}}{2\sin\beta} \qquad (7)$$

where

$$\beta = \sqrt{\Delta\alpha^2 + \Delta\phi_H^2\sin^2\frac{\sum\alpha}{2}}$$

It is required that $R_w > R_{we}$ for a deviation angle no greater than 12° while, for a deviation angle greater than 12°, in addition to the requirement that $R_w > R_{we}$, it is still required that the deviation angle variation of borehole section ΔL be less than 0.125°/25m, and that the length of borehole section ΔL be greater than 50m.

5.4.2.4 Deviation angle variation over any of the other borehole sections located above the pump setting TVD should be less than 10°/25m.

5.4.2.5 The determined pump-setting TVD should be capable to ensure a steady daily liquid production rate even when there is a change in well producing fluid level, water cut and so on.

6 Practice for grade selection and design of tapered sucker rod string

6.1 Grade selection principles of sucker rod

6.1.1 Grade selection of sucker rod should be based on well fluid properties and the type of load. Grades of sucker rod are listed in Table 3.

Table 3 Mechanical properties of sucker rod

Rod grade	K	C	D	H
Tensile strength of rod MPa	620～793	620～793	793～965	966～1136

6.1.2 Grade C rods are recommended for light-to-medium load wells with mild brine corrosion.

6.1.3 Grade K rods are recommended for medium-load applications in CO_2, H_2S, highly sandy or highly paraffinic wells.

6.1.4 Grade D or H rods are recommended for highly loaded wells with mild brine corrosion.

6.2 Design procedure for tapered sucker rod string

6.2.1 Approximately-equal-strength design of tapered sucker rod string

The modified Goodman's stress diagram is employed to design a sucker rod string, which had better to be a tapered one. Its number of stages and length of each stage may be found from Table B. 1 of Annex B or calculated by following equal-strength principle for every stage and minimizing weight of the string. Stress difference between stages of the string should be kept within 0. 5MPa. In a deep well or a well where a subsurface pump sized 70mm or larger is applied, a sinker bar may be added to the bottom of the string to avoid rod buckling.

6.2.1.1 Design of sinker bar

Follow C. 1. 1～C. 1. 6 of Annex C to design a sinker bar.

6.2.1.2 Design of tapered sucker rod design located above sinker bar

Its design procedure is given in C. 2 of Annex C.

6.2.2 Equal-strength design of tapered sucker rod string

6.2.2.1 Design of sinker bar

Follow C. 1. 1～C. 1. 6 and C. 1. 1～C. 1. 7 of Annex C to design a sinker bar for use in a vertical well and a deviated well, respectively.

6.2.2.2 Design of sucker rod string located above sinker bar

Follow C. 3 and C. 4 of Annex C to design a sucker rod string located above the sinker bar for use in a vertical well and a deviated well, respectively.

6.2.3 Example of design of tapered sucker rod string

Design of sucker rod string is exemplified in C. 5 of Annex C.

7 Configuration design of production string

7.1 Rod string

7.1.1 The rod string consists of polished rod, sucker rod string (one stage or multi-stage), plunger. See Fig. 1.

7.1.2 Due to the require end well condition or the string structure, corresponding downhole tools are installed in the string. See Fig. 2.

7.1.2.1 Connecting-tripping device is needed to be added between rod and plunger when tubing's ID is smaller than plunger's OD.

7.1.2.2 When bleeder is required, the control block or oil drain starter should be added at the proper location in rod string.

7.1.2.3 Parting preventer could be put in the neutralization point of rod string or the part where well bore or orientation angle variation rate is high.

7.1.2.4 Rod centralizers should be added to the part where rod wear problem has been found above or under the neutralization point.

Centralizers are usually installed under the neutralization point. And the spaces between centralizers increase from top to the bottom. The screw pitch of the rod string's helixcal bending can be calculated by equation (8):

$$P_n = [3.3(d_p^2 - d_o^2) \cdot (d_p/d_o)^4 \cdot (Sn/\mu)^2 \gamma_L \times 10^{-4} + 1770 d_p - 14] \times 10^{-2} \tag{8}$$

For deviation wells, the configuration of centralizers should meet the condition of equation (9):

$$W_{rf}/N_f > 50 \tag{9}$$

For the interval whose rate of overall angle change is less than 7°/30m, three centralizers per rod is needed. For the interval whose grads of overall angle change is larger than 7°/30m, or where paraffin deposit is serious.

7.1.2.5 For paraffin deposit wells, paraffin controller or paraffin scraper in rod string should be installed in the proper location of tubing.

7.1.2.6 In order to reduce the maximum load in hanger and cyclic load, impact damper might be installed in the proper location of rod string.

7.2 Tubing string

7.2.1 The basic structure of tubing string

From top to the bottom, basic tubing string consists of tubing, pump, screen pipe, tail pipe and plug. See Fig. 3.

7.2.2 Conventional tubing string

According to the requirement of well conditions, different downhole tools might be added into the conventional tubing string. See Fig. 4.

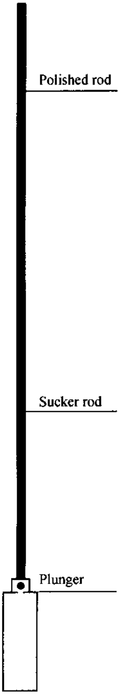


Fig. 1

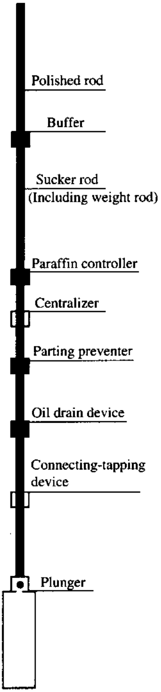


Fig. 2

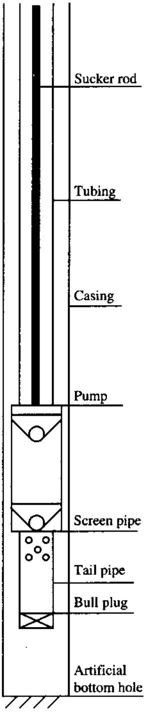


Fig. 3

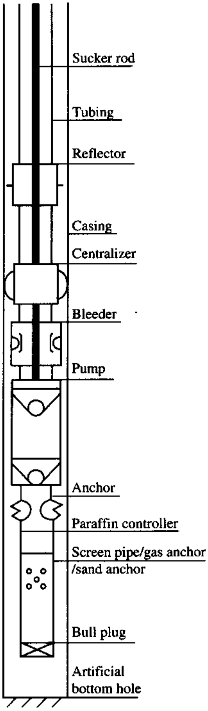


Fig. 4

7.2.2.1 For the a well with connecting-tripping device, connecting-tripping mandrel (also called tubing pup joint and connecting-tripping ring) is necessary to be placed above the pump.

7.2.2.2 Bleeder should be added to the lower part of tubing string for non-flowing wells.

7.2.2.3 For deeper pump location wells, tubing string should be anchored according to the tubing string condition.

7.2.2.4 Tubing centralizer is available to be installed in the lower part of tubing string to avoid the swing or helical bending of tubing. Tubing centralizer is needed when pump is set to deep well bore and the installation location could be got by equation (10):

$$h_n = \pi\sqrt{8\times10^{-6}EI/P_n} \qquad (10)$$

7.2.2.5 Paraffin controller should be installed between the pump and screen pipe, or in the proper location of the string for paraffin-troubled oil wells.

7.2.2.6 Screen pipe should be replaced by gas anchor for high gas liquid ratio wells or anti-gas treatments are needed.

7.2.2.7 Sand control screen should replace the conventional screen for sandy wells.

7.2.3 Selective production string

7.2.3.1 Selective zone production with back off string

If the long-term water plugging zone is determined, or the distance between pump depth and water plugging zone is larger as well as the producer doesn't belong to the casing deforming area, this kind of tubing string would be selected. See Fig. 5 And the number and type of the packers in the string depend on the status of separate zone production and whether the string needs to be set to bottom of the well or not.

7.2.3.2 Integrated tubing string for selective zone production

7.2.3.2.1 Two selective zone production tubing string structures: (1) Plugging upper zone & producing lower zone; (2) Plugging middle zone & producing upper and lower zones. See Fig. 6.

7.2.3.2.2 Plugging lower zone and producing upper zone. See Fig. 7.

7.2.3.2.3 Plugging upper and lower zones and producing middle zone. See Fig. 8.

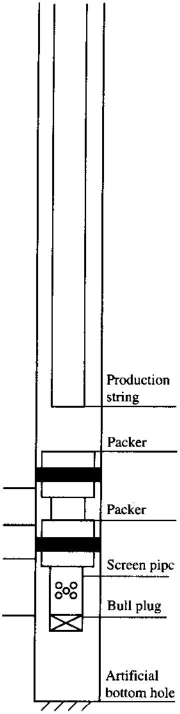


Fig. 5

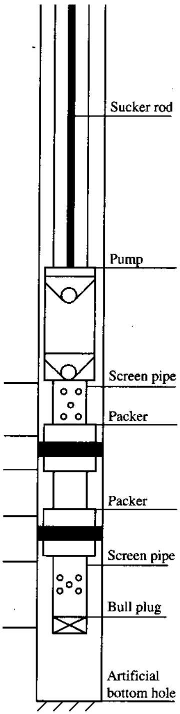


Fig. 6

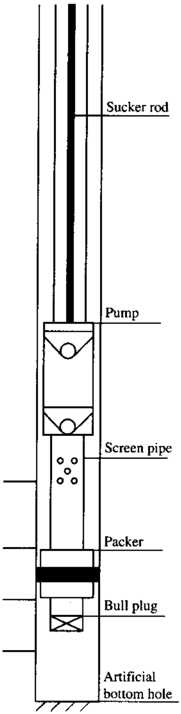


Fig. 7

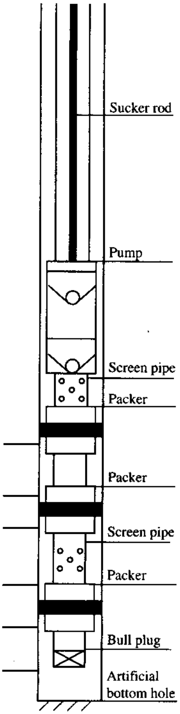


Fig. 8

7. 2. 4 Releasing Snubbing operation tubing string

Centralizer and poker are connected to the bottom of conventional producing tubing string. Release packer is set above the top boundary of perforation area. Under the release packer, a faucet is connected, then the screen pipe, tail pipe and plug. Wellhead mandrel is installed in the upper of the string. See Fig. 9.

7. 2. 5 Eccentricity testing string

For 140mm casing, when plunger OD is 56mm or smaller as well as eccentricity wellhead is applied, the conventional plug should be replaced by guide cone plug. See Fig. 10.

7. 2. 6 Thermal circulating string but killing well

For non-large-size casing wells in low reservoir pressure area, a packer is connected under the conventional producing string which is also seated above the top boundary of perforation part. A check valve is below the packer. See Fig. 11.

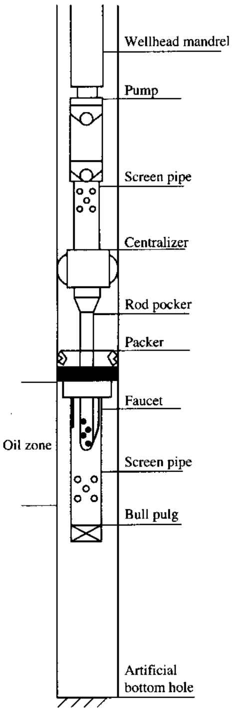


Fig. 9

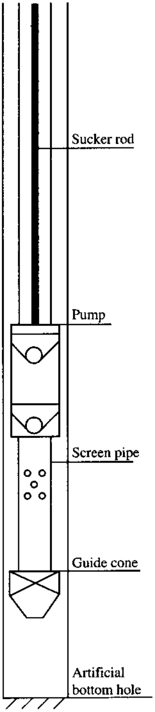


Fig. 10

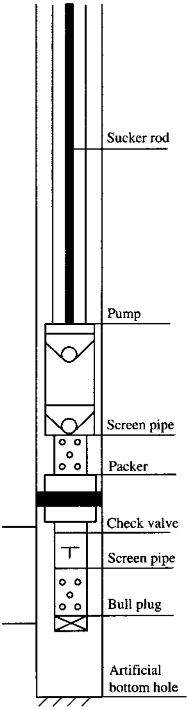


Fig. 11

7. 3 Proper tubing string selection

7. 3. 1 Snubbing string technology should be the first choice except the following special cases:

(1) Reservoir pressure is remarkable lower than the well's hydrostatic liquid column.

(2) Snubbing controller couldn't be installed on the wellhead.

(3) Treatment could only be implemented in case of well killing.

7.3.2 When eccentricity wellhead is installed, guide cone plug must be applied on the bottom of the string. And the distance between the tail of the string and the top boundary of perforation area should be larger than 15m. No connector is permitted to find in the scale of 8m under the hanger. The width of eccentricity should be larger than 35mm.

7.3.3 The bottom of gas lift string for spotting water zone should be 15m higher than the top boundary. In selecting the type of the mandrel below pump, the plugger should be sure to pass through the pump and testing apparatus.

7.3.4 The location of downhole tools in the string and the coupling in operation should be kept away from the sub-coupling of bleeder and composite string.

7.3.5 The selection of the fixed method of paraffin scraper limit block should take rod safety into account.

7.3.6 Anchor packer should be applied for release selective zone production string without running into the bottom hole, or the string should be fixed with the spider should be fixed. Packers are needed to be seated both above and below the plugging zone to keep balance for the release string running into the bottom hole.

7.3.7 For the release Snubbing (selective zone production) string, pumping string shouldn't be loaded on the release string while the distance as a 0.3m or larger should be remained.

8 Operation

8.1 Operation design

8.1.1 The Operation instructions are compiled according to the present status of oil well or geological project. If the operation instruction is needed to change, the operation can't be executed until the design department put forward to additional project or change notice and be double checked.

8.1.2 The format and requirements for operation design are shown as Annex D.

8.2 Operation preparation

Executing the well cleanout requirements in SY/T 5587.5—2004.

8.3 Pulling and running operation program, technical requirements

8.3.1 Well cleanout

Executing the well cleanout requirements in SY/T 5587.5—2004.

8.3.2 Well kill

Executing the well kill requirements in SY/T 5587.3—2004.

8.3.3 Pulling sucker rods

8.3.3.1 Well control must be done, well control devices muse be installed well. For a well with connecting-tripping device, pulling the first sucker rod must lift slowly so that connecting-tripping device can decoupling smoothly; for a well with oil drain valve, when oil drain valve is near bleeder, it must be pulled up slowly so that connecting-tripping device can switch smoothly. When encountering the resistant force in pulled up sucker rods, sucker rods can't be pulled strongly; after the reason should be investigated, make some measures to treat it.

8.3.3.2 When pulling sucker rods, each posts must match closely, prevent sucker rods from deforming and prevent some objects from falling in well bore.

8.3.3.3 Smoothly pulling sucker rods and piston. 4 sucker rods must used to build sucker rod bridge, each sucker rod must use at least 4 bridge base to erect, 10 pulled rods in a group is arranged, the length of sucker rod hanging end is no more than 1.0m, the height of sucker rod to ground is no less than 0.5m.

8.3.4 Pulling pipe strings

Executing the requirements of pulling pipe string in SY/T 5587.5—2004.

8.3.5 Paraffin Cutting & Drifting

Executing the drifting requirement in SY/T 5587.5—2004.

8.3.6 Displacing Flow

Executing displaced flow requirements in SY/T 5587.3—2004.

8.3.7 Detecting sand, sand washing

Executing SY/T 5587.5—2004.

8.3.8 Matching pipe strings

8.3.8.1 Clean tubing, sucker rods with steam to ensure running clean tubing, sucker rods and downhole tools.

8.3.8.2 Damaged thread, bent rod body, joint or serious wear rod body, other deformation sucker rod body are not permitted to run into well. Damaged thread, sand hole, fracture and wear tubing are not permitted to run into well. If necessary, failure strength of tubing and sucker rod must be detected.

8.3.8.3 For a 73mm plain tubing, ϕ59mm × 800mm inside caliper is used to drift tubing; for a ϕ89mm tubing, ϕ73mm × 800mm inside caliper is used to drift tubing, unqualified tubing is not permitted to run into well.

8.3.8.4 Tubing and sucker rod must measure 3 times and record, the error of less than 0.02% is regarded as qualification.

8.3.8.5 When assembling downhole tools, design, conformity certification and object muse be consistency. After double-checking, if no error, these tools can be run into well.

8.3.9 Running pipe string

Executing the requirements on running pipe string in SY/T 5587.5—2004.

8.3.10 Running sucker rod string

8.3.10.1 Sucker rod thread and contact surface must clean, the position and number of installing sucker rod centralize must accord with design requirement.

8.3.10.2 Tightening torque of sucker rod must conform with the specification in Table 4.

Table 4 Executive standard on sucker rod tightening torque

Sucker rod specification mm	Tightening Torque, kN • m	
	Stress is 245MPa	Stress is over 245MPa
16	0.30	0.33
19	0.48	0.53
22	0.72	0.79
25	1.10	1.22
29	1.52	1.67

8.3.10.3 Preventing excessive tightening torque and damaging sucker rod thread.

8.3.10.4 Smoothly and slowly run piston into pump barrel. For a well with connecting-tripping device, first connect the device, but after connecting, the height of sucker rod is not over height, prevent it decoupling. For a well with downhole switch, the switch must open according to usage requirement.

8.3.10.5 After piston setting into pump barrel, polished rod stretches below flange, and its length is no less than the sum of shock isolation space and maximum stroke. After piston setting in pump barrel, horse head is in lower dead point, ensuring polished rod stretch into mulehead hanger, its length is no more than 0.3m.

8.3.10.6 During running pipe strings, open flowing is forbidden.

8.3.11 Pumping test and transferring well

8.3.11.1 Horse head alights to wellhead, strictly prevent polished rod from bending, and adjust shock isolation space according to design requirement.

8.3.11.2 Pumping test, when closing all outlets, pressure is reached to 3MPa ~ 5MPa, pressure maintains for 15min, pressure drawdown of less than 0.3MPa is regarded as qualification. If unqualified, investigate the cause.

8.3.11.3 Change flow path, start to pump. If normal, transfer the well.

8.4 Compile Operation Summary

8.4.1 After finishing operation, compile operation summary in time.

8.4.2 The format of operation summary is shown as Annex E.

8.5 HSE Control

8.5.1 HSE control executes the standard of SY/T 6361—1998 and SY/T 6362—1998.

8.5.2 Operation Company must arrange a quality inspector who is in charge of field quality inspection. Each group has a part time quality inspector to check operation quality. Next procedure cannot be done until the previous procedure is qualified.

Annex A

(Informative)

Plotting of selection chart of beam pumping unit

A. 1 Theoretical bases of plotting of selection chart of beam pumping unit

The two basic parameters denoting the scope of application of beam pumping unit are pump setting depth and pump displacement.

A. 1. 1 Determination of maximum pump setting depth:

The three main factors limiting the maximum pump setting depth of a pumping equipment are polished rod load rating $[P_{\max}]$, reducer torque rating $[M_{\max}]$ and strength of sucker rod.

A. 1. 1. 1 Maximum pump-setting depth $L_{\max}$ limited by polished rod load rating $[P_{\max}]$ is given by

$$L_{\max} = \frac{[P_{\max}]}{\rho_{\mathrm{wL}} g (A_{\mathrm{p}} - A_{\mathrm{r1}}) + q_{\mathrm{r}}\left(1 + \frac{S_{\max} N_{\max}^2}{1790}\right)} \qquad (\mathrm{A.\,1})$$

A. 1. 1. 2 Maximum pump-setting depth $L_{\max}$ limited by reducer torque rating $[M_{\max}]$ is given by

$$L_{\max} = \frac{[M_{\max}] - 300 S_{\max}}{0.236 S_{\max}\left[\rho_{\mathrm{wL}} g (A_{\mathrm{p}} - A_{\mathrm{r1}}) + 2 q_{\mathrm{r}} \frac{S_{\max} N_{\max}^2}{1790}\right]} \qquad (\mathrm{A.\,2})$$

A. 1. 1. 3 Maximum pump-setting depth $L_{\max}$ limited by strength of sucker rod:

By means of the modified Goodman's stress diagram shown in Fig. A. 1, maximum stress allowable and stress range allowable of sucker rod under asymmetric cyclic loading is given by

$$\sigma_{\mathrm{rp,max}} = (aT + b\sigma_{\mathrm{r,min}})\ SF \qquad (\mathrm{A.\,3})$$

$$[\Delta\sigma] = \sigma_{\mathrm{rp,max}} - \sigma_{\mathrm{r,min}} \qquad (\mathrm{A.\,4})$$

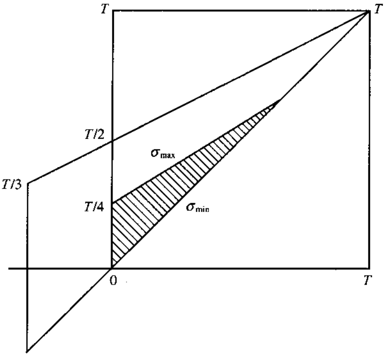


Fig. A. 1 Modified Goodman's stress diagram

For a tapered sucker rod string, the principle of equal utilization coefficient is applied to make the top of each stage equal in strength, namely

$$\frac{\sigma_{\mathrm{rp,max,L}}}{aT + b\sigma_{\mathrm{r,min,L}}} = \frac{\sigma_{\mathrm{rp,max,L+1}}}{aT + b\sigma_{\mathrm{r,min,L+1}}} \qquad (\mathrm{A.\,5})$$

thereby, yielding maximum pump setting depth of each stage and that of the whole string.

A. 1. 2 Maximum pump displacement is calculated by

$$Q_{\max} = 1440 A_{\mathrm{p}} S_{\mathrm{pmax}} N_{\max} \eta \qquad (\mathrm{A.\,6})$$

Where

$$S_{\mathrm{pmax}} = S_{\max} - \lambda + \lambda_i$$

$$\lambda = \frac{W_{\mathrm{L}} L_{\max}}{E}\left(\frac{1}{A_{\mathrm{r}}} + \frac{1}{A_{\mathrm{t}}}\right)$$

$$\lambda_i = \left(\frac{L_{\max}}{1915}\right)^2 \frac{S_{\max} N_{\max}^2}{1155}$$

For a tapered sucker rod string, it is only necessary to modify the first term in the expression determining the value of λ.

A. 2 Plotting procedure for sizing chart of beam pumping unit

A. 2. 1 For the convenience of plotting and application of the sizing chart, sort merge beam pumping units with the same PRL into short-stroke, medium-stroke and long-stroke ones.

Classify the 2 - 0.6 - 2.8 and 6 - 2.5 - 26 beam pumping units as a short-stroke and a medium-stroke one, respectively, and classify the 5 - 2.5 - 18 beam pumping unit as a separate one.

A.2.2 For each beam pumping unit size, calculate the maximum pump displacement and the three maximum pump setting depths for each combination with sucker rod string and pump size (the standard of GB/T 18607—2001 specifies 10 subsurface pump sizes) and find the smallest of the three pump setting depths, which is the one used to plot the sizing chart. The two values constitute a pair of coordinates in the sizing chart.

A.2.3 Plot the sizing chart for each category of beam pumping unit (Fig. A.2~Fig. A.5).

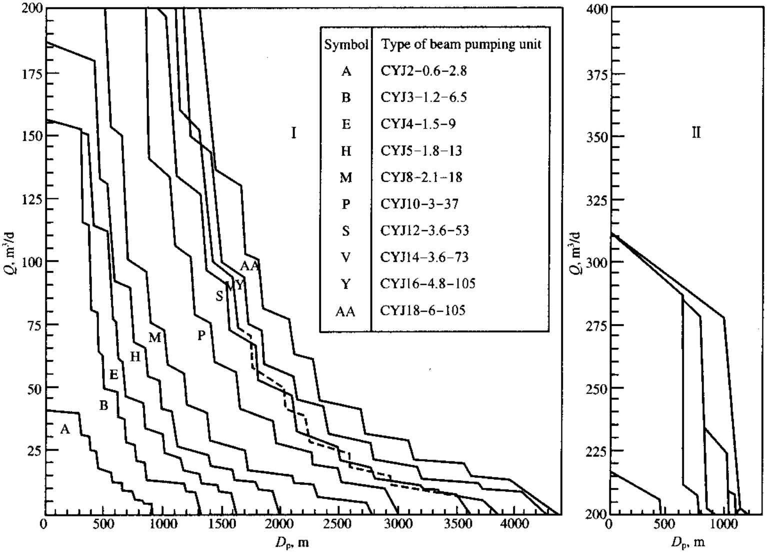


Fig. A.2 Sizing chart of beam pumping unit A

A.3 Assumed values of parameters during plotting of sizing chart of beam pumping unit

During plotting sizing chart of beam pumping unit, values of related parameters is set as follows:

$$\rho_{wL} = 950\text{kg/m}^3$$

$$D_{ps} = 200\text{m}$$

$$E = 2.058 \times 10^{11}\text{Pa}$$

$$T = 8 \times 10^{8}\text{Pa}$$

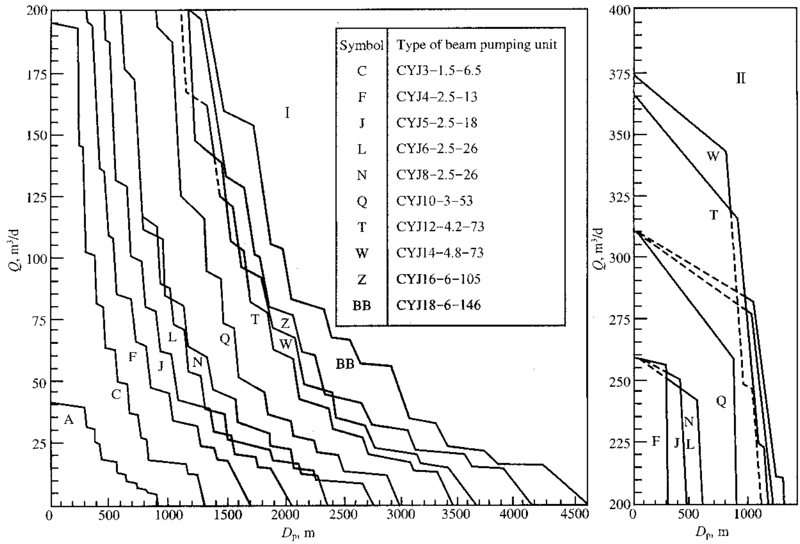
$$SF = 0.9$$

$$\eta = 0.85$$

It is assumed that the tubing string is anchored during plotting sizing chart of beam pumping unit.

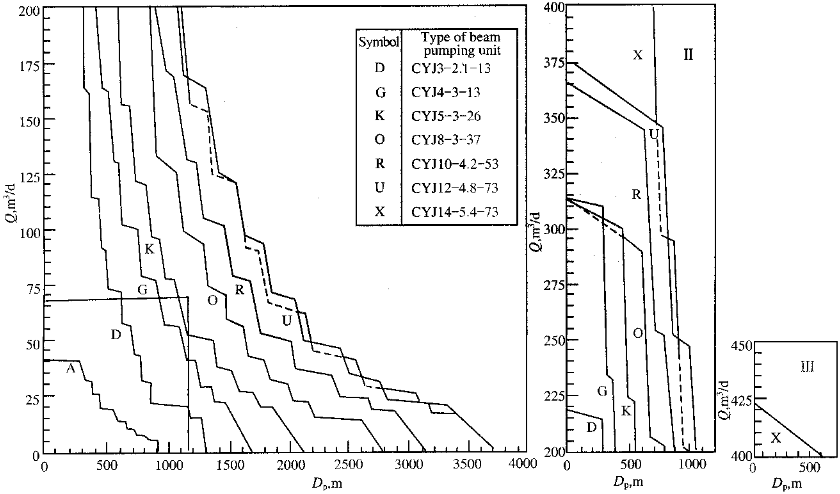
A.4 Assumed values of maximum strokes per minute

Maximum strokes per minute of beam pumping units is given in Table A.1.



Symbol	Type of beam pumping unit
C	CYJ3-1.5-6.5
F	CYJ4-2.5-13
J	CYJ5-2.5-18
L	CYJ6-2.5-26
N	CYJ8-2.5-26
Q	CYJ10-3-53
T	CYJ12-4.2-73
W	CYJ14-4.8-73
Z	CYJ16-6-105
BB	CYJ18-6-146

Fig. A. 3 Sizing chart of beam pumping unit B



Symbol	Type of beam pumping unit
D	CYJ3-2.1-13
G	CYJ4-3-13
K	CYJ5-3-26
O	CYJ8-3-37
R	CYJ10-4.2-53
U	CYJ12-4.8-73
X	CYJ14-5.4-73

Fig. A. 4 Sizing chart of beam pumping unit C

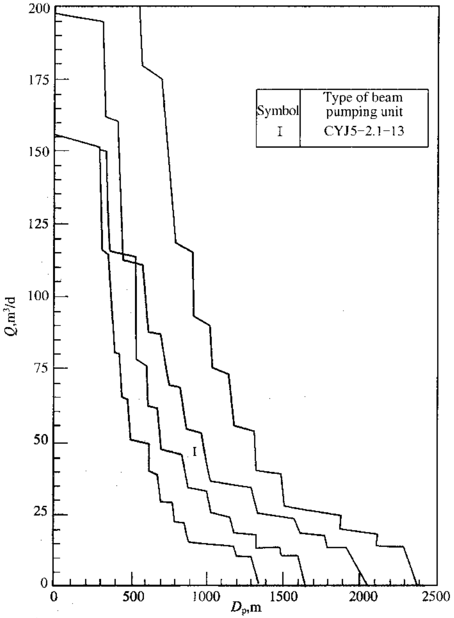


Fig. A. 5 Sizing chart of beam pumping unit D

Table A. 1 Basic parameters of beam pumping unit

No.	Unit size	Polished rod load rating 10kN	Maximum stroke length of polished rod m	Reducer torque rating kN • m	Maximum frequency of stroke min^{-1}
1	2-0.6-2.8	2	0.6	2.8	15
2	3-1.2-6.5	3	1.2	6.5	
3	3-1.5-6.5		1.5		
4	3-2.1-13		2.1	13	12
5	4-1.5-9	4	1.5	9.0	
6	4-2.5-13		2.5	13	
7	4-3-18		3.0	18	
8	5-1.8-13	5	1.8	13	
9	5-2.1-13		2.1	13	
10	5-2.5-18		2.5	18	
11	5-3-26		3.0	26	
12	6-2.5-26	6	2.5		

Table A. 1 (continued)

No.	Unit size	Polished rod load rating 10kN	Maximum stroke length of polished rod m	Reducer torque rating kN • m	Maximum frequency of stroke min^{-1}
13	8 - 2. 1 - 18	8	2. 1	18	12
14	8 - 2. 5 - 26		2. 5	26	
15	8 - 3 - 37		3. 0	37	
16	10 - 3 - 37	10			
17	10 - 3 - 53			53	10
18	10 - 4. 2 - 53	10	4. 2	53	
19	12 - 3. 6 - 53	12	3. 6		
20	12 - 4. 2 - 73		4. 2	73	
21	12 - 4. 8 - 73		4. 8		9
22	14 - 3. 6 - 73	14	3. 6		
23	14 - 4. 8 - 73		4. 8		
24	14 - 5. 4 - 73		5. 4		
25	16 - 4. 8 - 105	16	4. 8	105	6
26	16 - 6 - 105		6. 0		
27	18 - 6 - 105	18			
28	18 - 6 - 146			146	

A. 5 Example of sizing beam pumping unit

A well has an oil density of 0. 912g/cm^3 and a dynamic viscosity of 1100 mPa • s. The well produces with a water cut of 0. Which size of beam pumping unit should be chosen to ensure that the well produces with a designed production of 70m^3/d at a pump setting depth of 1150m?

A. 5. 1 Sizing chart selection

Relatively high viscosity of the well dictates a long-stroke beam pumping unit for use in the well, so Fig. A. 4 should be applied.

A. 5. 2 Sizing of beam pumping unit

In Fig. A. 4, locate the point of 1150m corresponding to the pump setting depth on the abscissa axis and the point of 70 m^3/d corresponding to the designed well daily oil production rate on the ordinate axis, and from these two points, draw two lines perpendicular to the abscissa axis and the ordinate axis, respectively. Their intersection point falls within the range of choice of beam pumping unit sized 8 - 3 - 37, so a large-size beam pumping unit, 10 - 4. 2 - 53, may be chosen for use in the well.

Annex B

(Informative)

Tabulated design of tapered sucker rod string

Tabulated design of tapered sucker rod string see Table B. 1.

Table B. 1 Tabulated design of tapered sucker rod string

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																											
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
32	≥1.6 ≤2.7	54	2363	—	—	—	—	64	36	2063	—	—	—	—	62	38	1793	—	—	—	—	59	41	1553	—	—	—	—	55	45
		64	2903	—	—	—	47	45	8	2573	—	—	—	47	41	12	2263	—	—	—	47	38	15	1973	—	—	—	45	35	19
		65	2843	—	—	—	47	53	—	2473	—	—	—	48	52	—	2123	—	—	—	47	53	—	1813	—	—	—	46	54	—
		76	3233	—	—	37	63	—	—	2803	—	—	39	61	—	—	2393	—	—	39	61	—	—	2023	—	—	38	62	—	—
		75	3943	—	—	57	30	13	—	3043	—	—	38	35	27	—	2653	—	—	39	33	28	—	2283	—	—	38	32	30	—
		87	3533	—	30	70	—	—	—	3053	—	32	68	—	—	—	2603	—	33	67	—	—	—	2183	—	33	67	—	—	—
		86	4418	—	47	26	27	—	—	3403	—	31	31	38	—	—	2953	—	33	29	38	—	—	2513	—	32	28	40	—	—
		85	4433	—	46	26	24	4	—	3573	—	31	30	26	13	—	3153	—	32	29	24	15	—	2753	—	33	28	22	17	—
		97	4933	45	21	34	—	—	—	3833	32	25	43	—	—	—	3323	34	24	42	—	—	—	2823	34	23	43	—	—	—
		96	5143	24	41	21	14	—	—	4563	46	21	19	14	—	—	3643	34	24	21	21	—	—	3163	35	23	20	22	—	—
		95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3773	34	24	21	16	5	—	3343	36	23	19	15	7	—
	>2.7 ≤3.3	54	2303	—	—	—	—	62	38	1973	—	—	—	—	59	41	1683	—	—	—	—	57	43	1414	—	—	—	—	53	47
		64	2833	—	—	—	46	45	9	2463	—	—	—	46	40	14	2113	—	—	—	45	37	18	1794	—	—	—	43	35	22
		65	2773	—	—	—	47	53	—	2353	—	—	—	46	54	—	1973	—	—	—	45	55	—	1634	—	—	—	43	57	—
		76	3153	—	—	37	63	—	—	2653	—	—	38	62	—	—	2203	—	—	37	63	—	—	1814	—	—	36	64	—	—

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																											
			$2\text{min}^{-1}\leqslant n\leqslant 5\text{min}^{-1}$							$5\text{min}^{-1}< n\leqslant 8\text{min}^{-1}$							$8\text{min}^{-1}< n\leqslant 11\text{min}^{-1}$							$11\text{min}^{-1}< n\leqslant 15\text{min}^{-1}$						
			L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
32	>2.7 ≤3.3	64	3353	—	—	—	35	37	28	2883	—	—	—	37	34	29	2443	—	—	—	36	33	31	2044	—	—	—	35	31	34
		76	3443	—	—	30	70	—	—	2893	—	—	31	69	—	—	2393	—	—	31	69	—	—	1954	—	—	31	69	—	—
		86	3763	—	28	30	42	—	—	3213	—	30	30	40	—	—	2703	—	30	28	42	—	—	2234	—	30	27	43	—	—
		85	3883	—	28	30	29	13	—	3383	—	30	29	26	15	—	2903	—	30	28	24	18	—	2444	—	30	27	23	20	—
		97	4223	29	24	47	—	—	—	3603	31	24	45	—	—	—	3023	32	24	44	—	—	—	2484	32	23	45	—	—	—
		96	4773	37	22	22	19	—	—	3883	31	24	22	23	—	—	3313	32	23	21	24	—	—	2774	33	22	19	26	—	—
		95	4773	37	22	22	19	—	—	3973	30	24	22	19	5	—	3463	31	23	21	17	8	—	2954	33	22	19	16	10	—
	>3.3 ≤4.2	54	2243	—	—	—	—	62	38	1863	—	—	—	—	57	43	1534	—	—	—	—	54	46	1284	—	—	—	—	51	49
		64	2753	—	—	—	45	44	11	2323	—	—	—	44	39	17	1924	—	—	—	42	36	22	1614	—	—	—	40	34	26
		65	2693	—	—	—	46	54	—	2213	—	—	—	45	55	—	1794	—	—	—	43	57	—	1464	—	—	—	40	60	—
		76	3053	—	—	36	64	—	—	2483	—	—	36	64	—	—	1994	—	—	36	64	—	—	1604	—	—	34	66	—	—
		75	3253	—	—	35	36	29	—	2703	—	—	35	34	31	—	2204	—	—	34	32	34	—	1814	—	—	33	30	37	—
		87	3333	—	30	70	—	—	—	2703	—	31	69	—	—	—	2154	—	30	70	—	—	—	1724	—	29	71	—	—	—
		86	3633	—	28	30	42	—	—	2993	—	29	29	42	—	—	2424	—	29	27	44	—	—	1954	—	28	26	46	—	—
		85	3763	—	27	30	29	14	—	3163	—	29	28	26	17	—	2614	—	28	27	24	21	—	2154	—	27	26	23	24	—
		97	4083	29	24	47	—	—	—	3353	30	24	46	—	—	—	2704	31	23	46	—	—	—	2164	30	22	48	—	—	—
		96	4323	28	23	24	25	—	—	3613	30	23	22	25	—	—	2954	30	22	21	27	—	—	2404	29	21	20	30	—	—
		95	4363	29	23	24	22	4	—	3713	28	23	22	19	8	—	3104	30	22	20	17	11	—	2584	29	21	19	17	14	—

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																											
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
32	>4.2 ≤5.0	54	2203	—	—	—	—	61	39	1813	—	—	—	—	56	44	1464	—	—	—	—	52	48	1214	—	—	—	—	49	51
		64	2713	—	—	—	45	43	12	2253	—	—	—	43	39	18	1844	—	—	—	41	36	23	1524	—	—	—	39	33	28
		65	2643	—	—	—	45	55	—	2133	—	—	—	44	56	—	1704	—	—	—	42	58	—	1374	—	—	—	39	61	—
		76	2993	—	—	36	64	—	—	2393	—	—	36	64	—	—	1884	—	—	35	65	—	—	1504	—	—	33	67	—	—
		75	3193	—	—	34	36	30	—	2603	—	—	35	33	32	—	2094	—	—	33	31	36	—	1694	—	—	32	29	39	—
		87	3273	—	30	70	—	—	—	2593	—	30	70	—	—	—	2034	—	29	71	—	—	—	1604	—	28	72	—	—	—
		86	3563	—	28	29	43	—	—	2873	—	29	29	42	—	—	2284	—	28	27	45	—	—	1824	—	27	26	47	—	—
		85	3693	—	27	29	29	15	—	3043	—	27	28	26	19	—	2474	—	28	26	24	22	—	2014	—	27	25	22	26	—
		97	4003	29	24	47	—	—	—	3213	30	23	47	—	—	—	2544	30	22	48	—	—	—	2004	29	21	50	—	—	—
		96	4233	27	23	24	26	—	—	3463	28	23	22	27	—	—	2784	30	22	20	28	—	—	2234	28	21	19	32	—	—
		95	4283	27	23	24	22	4	—	3583	29	22	21	19	9	—	2934	30	21	20	17	12	—	2404	29	20	19	17	15	—
	>5.0 ≤6.0	54	2143	—	—	—	—	60	40	1694	—	—	—	—	55	45	1354	—	—	—	—	51	49	1805	—	—	—	—	47	53
		64	2633	—	—	—	44	43	13	2104	—	—	—	42	38	20	1694	—	—	—	39	35	26	1365	—	—	—	37	33	30
		65	2553	—	—	—	45	55	—	1984	—	—	—	43	57	—	1554	—	—	—	41	59	—	1225	—	—	—	48	62	—
		76	2893	—	—	36	64	—	—	2224	—	—	35	65	—	—	1714	—	—	33	67	—	—	1335	—	—	32	68	—	—
		75	3083	—	—	34	35	31	—	2424	—	—	33	33	34	—	1904	—	—	32	30	38	—	1505	—	—	30	29	41	—
		78	3163		30	70	—	—	—	2414	—	30	70	—	—	—	1844	—	29	71	—	—	—	1415	—	28	72	—	—	—

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																											
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
32	>5.0 ≤6.0	86	3443	—	29	29	43	—	—	2674	—	28	28	44	—	—	2074	—	27	26	47	—	—	1605	—	26	25	49	—	—
		85	3583	—	27	28	28	16	—	2834	—	28	27	25	20	—	2244	—	26	25	24	25	—	1785	—	25	24	22	29	—
		97	3863	28	24	47	—	—	—	2984	29	23	48	—	—	—	2294	29	22	49	—	—	—	1765	28	21	51	—	—	—
		96	4093	27	23	23	26	—	—	3224	29	22	21	28	—	—	2514	28	21	20	31	—	—	1965	27	20	19	34	—	—
		95	4152	27	22	23	21	6	—	3334	28	22	21	19	10	—	2664	26	21	20	18	15	—	2125	27	20	18	17	18	—
38	≥1.6 ≤2.7	54	1923	—	—	—	—	73	27	1703	—	—	—	—	69	31	1493	—	—	—	—	65	35	1303	—	—	—	—	59	41
		65	2383	—	—	—	55	45	—	2083	—	—	—	54	46	—	1803	—	—	—	52	48	—	1553	—	—	—	—	49	51
		64	2383	—	—	—	55	45	—	2083	—	—	—	54	46	0	1863	—	—	—	51	39	10	1643	—	—	—	48	37	15
		76	2783	—	—	42	58	—	—	2413	—	—	43	57	—	—	2073	—	—	43	57	—	—	1763	—	—	41	59	—	—
		75	2873	—	—	42	41	17	—	2543	—	—	42	38	20	—	2223	—	—	42	35	23	—	1933	—	—	41	33	26	—
		87	3103	—	34	66	—	—	—	2693	—	36	64	—	—	—	2293	—	36	64	—	—	—	1933	—	35	65	—	—	—
		86	3763	—	54	28	18	—	—	2913	—	35	33	32	—	—	2533	—	36	31	33	—	—	2173	—	36	29	35	—	—
		85	3763	—	54	28	18	0	—	2973	—	34	33	27	6	—	2633	—	36	31	24	9	—	2303	—	35	29	23	13	—
		98	3523	35	65	—	—	—	—	3063	37	63	—	—	—	—	2613	37	63	—	—	—	—	2193	37	63	—	—	—	—
		97	4343	51	23	26	—	—	—	3353	35	27	38	—	—	—	2903	37	26	37	—	—	—	2483	37	25	38	—	—	—
		96	4363	50	23	22	5	—	—	3513	35	26	24	15	—	—	3103	38	25	21	16	—	—	2693	38	24	20	18	—	—

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																											
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
38	>2.7 ≤3.3	54	1893	—	—	—	—	73	27	1633	—	—	—	—	66	34	1413	—	—	—	—	62	38	1204	—	—	—	—	58	42
		65	2333	—	—	—	54	46	—	1993	—	—	—	52	48	—	1683	—	—	—	49	51	—	1414	—	—	—	46	54	—
		64	—	—	—	—	—	—	—	2023	—	—	—	51	42	7	1753	—	—	—	48	39	13	1514	—	—	—	46	36	18
		76	2713	—	—	42	58	—	—	2293	—	—	42	58	—	—	1923	—	—	40	60	—	—	1594	—	—	38	62	—	—
		75	2813	—	—	41	41	18	—	2423	—	—	41	37	22	—	2073	—	—	40	34	26	—	1754	—	—	38	32	30	—
		87	3023	—	34	66	—	—	—	2543	—	35	65	—	—	—	2113	—	34	66	—	—	—	1744	—	33	67	—	—	—
		86	3223	—	33	34	34	—	—	2763	—	33	32	35	—	—	2333	—	33	30	37	—	—	1954	—	32	28	40	—	—
		85	3253	—	32	34	30	4	—	2833	—	34	32	26	8	—	2443	—	33	29	25	13	—	2084	—	32	28	24	16	—
		98	3433	34	66	—	—	—	—	2893	36	64	—	—	—	—	2403	36	64	—	—	—	—	1964	35	65	—	—	—	—
		97	3703	33	27	40	—	—	—	3163	34	26	40	—	—	—	2663	35	25	40	—	—	—	2204	34	24	42	—	—	—
		96	3823	33	26	26	15	—	—	3323	34	26	23	17	—	—	2843	35	25	21	19	—	—	2394	35	23	20	22	—	—
		95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2903	35	24	21	16	4	—	2494	34	23	20	16	7	—
	>3.3 ≤4.2	54	1843	—	—	—	—	71	29	1553	—	—	—	—	63	37	1304	—	—	—	—	59	41	1104	—	—	—	—	55	45
		65	2263	—	—	—	53	47	—	1873	—	—	—	50	50	—	1544	—	—	—	46	54	—	1284	—	—	—	43	57	—
		64	—	—	—	—	—	—	—	1923	—	—	—	49	41	10	1624	—	—	—	46	38	16	1374	—	—	—	42	36	22
		76	2623	—	—	41	59	—	—	2153	—	—	40	60	—	—	1744	—	—	38	62	—	—	1424	—	—	37	63	—	—
		75	2723	—	—	40	40	20	—	2283	—	—	39	36	25	—	1894	—	—	38	33	29	—	1574	—	—	36	31	33	—

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																											
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
38	>3.3 ≤4.2	87	2923	—	34	66	—	—	—	2383	—	34	66	—	—	—	1914	—	33	67	—	—	—	1554	—	31	69	—	—	—
		86	3123	—	32	33	35	—	—	2583	—	32	31	37	—	—	2114	—	31	29	40	—	—	1734	—	30	27	43	—	—
		85	3153	—	32	33	30	5	—	2663	—	32	30	27	11	—	2224	—	31	28	25	16	—	1864	—	30	27	23	20	—
		98	3323	34	66	—	—	—	—	2703	35	65	—	—	—	—	2164	34	66	—	—	—	—	1734	33	67	—	—	—	—
		97	3573	32	27	41	—	—	—	2953	33	25	42	—	—	—	2394	33	24	43	—	—	—	1934	32	23	45	—	—	—
		96	3703	32	26	26	16	—	—	3103	33	25	23	19	—	—	2564	32	24	21	23	—	—	2114	32	22	20	26	—	—
		95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2634	32	24	21	17	6	—	2214	31	22	20	17	10	—
	>4.2 ≤5.0	54	1813	—	—	—	—	69	31	1513	—	—	—	—	62	38	1244	—	—	—	—	57	43	1044	—	—	—	—	52	48
		65	2223	—	—	—	52	48	—	1813	—	—	—	49	51	—	1474	—	—	—	45	55	—	1204	—	—	—	42	58	—
		64	—	—	—	—	—	—	—	1873	—	—	—	48	41	11	1554	—	—	—	44	38	18	1304	—	—	—	41	35	24
		76	2573	—	—	41	59	—	—	2073	—	—	40	60	—	—	1664	—	—	37	63	—	—	1344	—	—	35	65	—	—
		75	2683	—	40	40	20	—	—	2203	—	—	38	36	26	—	1804	—	—	37	33	30	—	1484	—	—	34	30	36	—
		87	2873	—	33	67	—	—	—	2023	—	33	67	—	—	—	1814	—	31	69	—	—	—	1444	—	30	70	—	—	—
		86	3063	—	32	33	35	—	—	2493	—	31	30	39	—	—	2004	—	30	28	40	—	—	1614	—	29	27	44	—	—
		85	3103	—	32	32	30	6	—	2583	—	32	30	26	12	—	2114	—	29	28	25	18	—	1744	—	28	26	24	22	—
		98	3263	34	66	—	—	—	—	2593	34	66	—	—	—	—	2044	34	66	—	—	—	—	1614	32	68	—	—	—	—
		97	3503	32	26	42	—	—	—	2833	33	25	42	—	—	—	2254	32	24	44	—	—	—	1804	31	22	47	—	—	—

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																											
			$2\text{min}^{-1}\leqslant n\leqslant 5\text{min}^{-1}$							$5\text{min}^{-1}< n\leqslant 8\text{min}^{-1}$							$8\text{min}^{-1}< n\leqslant 11\text{min}^{-1}$							$11\text{min}^{-1}< n\leqslant 15\text{min}^{-1}$						
			$L_{\max}$ m	Sucker rod size mm						$L_{\max}$ m	Sucker rod size mm						$L_{\max}$ m	Sucker rod size mm						$L_{\max}$ m	Sucker rod size mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
38	>4.2 ≤5.0	96	3633	32	26	25	17	—	—	2993	32	24	23	21	—	—	2424	32	23	21	24	—	—	1974	30	22	20	28	—	—
		95	—	—	—	—	—	—	—	3023	33	24	22	18	3	—	2504	31	23	21	17	8	—	2074	30	23	20	17	12	—
	>5.0 ≤6.0	54	1763	—	—	—	—	68	32	1433	—	—	—	—	60	40	1164	—	—	—	—	54	46	955	—	—	—	—	50	50
		65	2163	—	—	—	51	49	—	1713	—	—	—	47	53	—	1354	—	—	—	44	56	—	1085	—	—	—	41	59	—
		64	—	—	—	—	—	—	—	1773	—	—	—	46	40	14	1444	—	—	—	42	37	21	1185	—	—	—	39	35	26
		76	2493	—	—	40	60	—	—	1943	—	—	38	62	—	—	1514	—	—	36	64	—	—	1195	—	—	33	67	—	—
		75	2603	—	—	40	38	22	—	2083	—	—	37	35	28	—	1654	—	—	35	32	33	—	1325	—	—	32	30	38	—
		87	2773	—	33	67	—	—	—	2143	—	32	68	—	—	—	1654	—	30	70	—	—	—	1285	—	29	71	—	—	—
		86	2963	—	31	32	37	—	—	2333	—	30	30	40	—	—	1824	—	29	28	43	—	—	1445	—	28	26	46	—	—
		85	3013	—	31	32	29	8	—	2423	—	30	29	26	15	—	1944	—	29	27	24	20	—	1565	—	27	26	23	24	—
		98	3153	34	66	—	—	—	—	2423	33	67	—	—	—	—	1854	32	68	—	—	—	—	1435	31	69	—	—	—	—
		97	3393	32	26	42	—	—	—	2643	31	25	44	—	—	—	2044	31	23	46	—	—	—	1595	29	22	49	—	—	—
		96	3513	31	25	25	19	—	—	2803	32	24	22	22	—	—	2204	31	22	21	27	—	—	1755	28	21	19	30	—	—
		95	—	—	—	—	—	—	—	2845	31	24	22	18	5	—	2294	30	22	20	17	10	—	1855	29	20	19	17	15	—
44	≥1.6 ≤2.7	54	1603	—	—	—	—	83	17	1423	—	—	—	—	75	25	1263	—	—	—	—	69	31	1123	—	—	—	—	64	36
		65	2013	—	—	—	62	38	—	1773	—	—	—	59	41	—	1543	—	—	—	55	45	—	1343	—	—	—	52	48	—
		64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1393	—	—	—	51	38	11

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																											
			$2min^{-1} \leqslant n \leqslant 5min^{-1}$							$5min^{-1} < n \leqslant 8min^{-1}$							$8min^{-1} < n \leqslant 11min^{-1}$							$11min^{-1} < n \leqslant 15min^{-1}$						
			L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
44	≥1. 6 ≤2. 7	76	2393	—	—	48	52	—	—	2083	—	—	48	52	—	—	1803	—	—	46	54	—	—	1553	—	—	43	57	—	—
		75	2423	—	—	47	45	8	—	2153	—	—	48	39	13	—	1893	—	—	46	36	18	—	1663	—	—	44	34	22	—
		87	2723	—	39	61	—	—	—	2363	—	39	61	—	—	—	2023	—	39	61	—	—	—	1723	—	37	63	—	—	—
		86	2843	—	38	38	24	—	—	2503	—	39	35	26	—	—	2183	—	38	33	29	—	—	1893	—	37	31	32	—	—
		85	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2233	—	39	32	24	5	—	1963	—	37	31	23	9	—
		98	3143	39	61	—	—	—	—	2733	40	60	—	—	—	—	2333	40	60	—	—	—	—	1973	39	61	—	—	—	—
		97	3833	59	25	16	—	—	—	2933	38	29	32	—	—	—	2553	40	27	33	—	—	—	2183	39	26	35	—	—	—
		96	—	—	—	—	—	—	—	3003	39	29	24	9	—	28	2653	39	27	22	12	—	—	2323	40	25	20	15	—	—
	>2. 7 ≤3. 3	54	1573	—	—	—	—	81	19	1373	—	—	—	—	72	—	1203	—	—	—	—	66	34	1044	—	—	—	—	61	39
		65	1973	—	—	—	61	39	—	1703	—	—	—	58	42	—	1453	—	—	—	53	47	—	1244	—	—	—	50	50	—
		64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1453	—	—	—	48	42	10	1264	—	—	—	44	40	16
		76	2333	—	—	47	53	—	—	1993	—	—	46	54	—	—	1683	—	—	43	57	—	—	1414	—	—	41	59	—	—
		75	2373	—	—	47	44	9	—	2063	—	—	45	39	16	—	1773	—	—	43	36	21	—	1524	—	—	41	33	26	—
		87	2653	—	38	62	—	—	—	2243	—	38	62	—	—	—	1883	—	37	63	—	—	—	1564	—	35	65	—	—	—
		86	2773	—	37	37	26	—	—	1383	—	37	34	29	—	—	2083	—	36	32	32	—	—	1714	—	34	30	36	—	—
		85	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2083	—	36	32	24	8	—	1794	—	34	30	24	12	—
		98	3063	38	62	—	—	—	—	2583	39	61	—	—	—	—	2153	38	62	—	—	—	—	1784	37	63	—	—	—	—

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																											
			$2\text{min}^{-1}\leq n\leq 5\text{min}^{-1}$							$5\text{min}^{-1}< n\leq 8\text{min}^{-1}$							$8\text{min}^{-1}< n\leq 11\text{min}^{-1}$							$11\text{min}^{-1}< n\leq 15\text{min}^{-1}$						
			$L_{\max}$ m	Sucker rod size mm						$L_{\max}$ m	Sucker rod size mm						$L_{\max}$ m	Sucker rod size mm						$L_{\max}$ m	Sucker rod size mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
44	>2.7 ≤3.3	97	3243	37	30	33	—	—	—	2773	38	28	34	—	—	—	2353	38	26	36	—	—	—	1964	36	25	39	—	—	—
		96	3283	37	29	27	7	—	—	2863	38	28	23	11	—	—	2463	37	26	22	15	—	—	2094	36	24	21	19	—	—
	>3.3 ≤4.2	54	1543	—	—	—	—	79	21	1313	—	—	—	—	69	31	1114	—	—	—	—	62	38	964	—	—	—	—	58	42
		65	1923	—	—	—	59	41	—	1613	—	—	—	55	45	—	1344	—	—	—	51	49	—	1134	—	—	—	46	54	—
		64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1344	—	—	—	44	42	14	1194	—	—	—	45	37	18
		76	2273	—	—	46	54	—	—	1873	—	—	44	56	—	—	1544	—	—	41	59	—	—	1274	—	—	38	62	—	—
		75	2313	—	—	46	43	11	—	1953	—	—	43	38	19	—	1634	—	—	41	35	24	—	1384	—	—	37	33	30	—
		87	2573	—	37	63	—	—	—	2103	—	37	63	—	—	—	1714	—	35	65	—	—	—	1394	—	33	67	—	—	—
		86	2693	—	37	36	27	—	—	2243	—	35	33	31	—	—	1854	—	33	31	36	—	—	1534	—	32	29	39	—	—
		85	—	—	—	—	—	—	—	2273	—	36	33	26	6	—	1914	—	34	30	25	11	—	1624	—	32	28	24	16	—
		98	2963	38	62	—	—	—	—	2423	38	62	—	—	—	—	1954	36	64	—	—	—	—	1584	35	65	—	—	—	—
		97	3133	36	29	35	—	—	—	2603	37	27	36	—	—	—	2124	35	25	40	—	—	—	1744	33	24	43	—	—	—
		96	3183	36	29	27	8	—	—	2693	36	27	23	14	—	—	2244	35	25	22	18	—	—	1864	31	23	21	25	—	—
	≥5.0 <4.2	54	1523	—	—	—	—	78	22	1283	—	—	—	—	68	32	1074	—	—	—	—	61	39	914	—	—	—	—	55	45
		65	1893	—	—	—	59	41	—	1563	—	—	—	53	47	—	1284	—	—	—	48	52	—	1074	—	—	—	44	56	—
		64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1314	—	—	—	46	40	14	1134	—	—	—	44	37	19
		76	2233	—	—	46	54	—	—	1813	—	—	43	57	—	—	1464	—	—	40	60	—	—	1204	—	—	37	63	—	—
		75	2273	—	—	45	43	12	—	1893	—	—	41	38	21	—	1564	—	—	39	35	26	—	1304	—	—	37	32	31	—

Table B.1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																											
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$							$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$							$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$							$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$						
			L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm						L_{max} m	Sucker rod size mm					
				29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13		29	25	22	19	16	13
44	>4.2 ≤5.0	87	2523	—	37	63	—	—	—	2033	—	35	65	—	—	—	1624	—	34	66	—	—	—	1314	—	31	69	—	—	—
		86	2643	—	36	36	28	—	—	2163	—	34	33	33	—	—	1764	—	32	30	38	—	—	1444	—	30	28	42	—	—
		85	—	—	—	—	—	—	—	2203	—	35	32	26	7	—	1834	—	32	30	25	13	—	1534	—	31	28	23	18	—
		98	2903	37	63	—	—	—	—	2333	37	63	—	—	—	—	1844	36	64	—	—	—	—	1474	34	66	—	—	—	—
		97	3073	36	29	35	—	—	—	2503	35	27	38	—	—	—	2014	34	25	41	—	—	—	1634	33	23	44	—	—	—
	>5.0 ≤6.0	96	3133	36	29	26	9	—	—	2593	35	26	24	15	—	—	2124	34	24	22	20	—	—	1754	31	23	21	25	—	—
		54	1483	—	—	—	—	76	24	1214	—	—	—	—	65	35	1014	—	—	—	—	59	41	835	—	—	—	—	53	47
		65	1843	—	—	—	58	42	—	1474	—	—	—	52	48	—	1194	—	—	—	46	54	—	975	—	—	—	43	57	—
		64	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1244	—	—	—	44	39	17	1005	—	—	—	36	39	25
		76	2163	—	—	45	55	—	—	1704	—	—	42	58	—	—	1354	—	—	38	62	—	—	1085	—	—	35	65	—	—
		75	2213	—	—	44	42	14	—	1784	—	—	41	36	23	—	1444	—	—	36	34	30	—	1185	—	—	35	31	34	—
		87	2443	—	36	64	—	—	—	1904	—	35	65	—	—	—	1484	—	32	68	—	—	—	1175	—	30	70	—	—	—
		86	2563	—	35	36	29	—	—	2034	—	33	32	35	—	—	1614	—	31	29	40	—	—	1295	—	29	27	44	—	—
		85	—	—	—	—	—	—	—	2084	—	33	31	26	9	—	1694	—	31	28	25	16	—	1385	—	29	26	24	21	—
		98	2813	37	63	—	—	—	—	2174	36	64	—	—	—	—	1684	34	66	—	—	—	—	1315	32	68	—	—	—	—
		97	2973	35	28	37	—	—	—	2334	34	26	40	—	—	—	1834	33	24	43	—	—	—	1455	31	23	46	—	—	—
		96	3043	35	28	26	11	—	—	2434	35	25	23	17	—	—	1954	33	23	21	23	—	—	1565	31	22	20	27	—	—
		95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1984	30	24	21	18	7	—	1635	31	21	20	17	11	—

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																			
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$						$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$						$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$						$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$					
			$L_{\max}$ m	Sucker rod size mm					$L_{\max}$ m	Sucker rod size mm					$L_{\max}$ m	Sucker rod size mm					$L_{\max}$ m	Sucker rod size mm				
				29	25	22	19	16		29	25	22	19	16		29	25	22	19	16		29	25	22	19	16
56	≥1.6 ≤2.7	65	1493	—	—	—	77	23	1324	—	—	—	70	30	1174	—	—	—	64	36	1035	—	—	—	59	41
		76	1813	—	—	60	40	—	1584	—	—	56	44	—	1394	—	—	53	47	—	1215	—	—	49	51	—
		75	—	—	—	—	—	—	—	—	—	—	—	—	1424	—	—	53	38	9	1255	—	—	48	37	15
		87	2113	—	48	52	—	—	1844	—	46	54	—	—	1594	—	44	56	—	—	1375	—	41	59	—	—
		86	2143	—	37	44	9	—	1894	—	46	39	15	—	1664	—	44	35	21	—	1455	—	41	34	25	—
		98	2503	47	53	—	—	—	2174	47	53	—	—	—	1874	45	54	—	—	—	1605	43	57	—	—	—
		97	2563	46	35	19	—	—	2264	46	32	22	—	—	1974	45	29	26	—	—	1715	44	27	29	—	—
	>2.7 ≤3.3	65	1463	—	—	—	74	26	1274	—	—	—	66	34	1114	—	—	—	60	40	975	—	—	—	55	45
		76	1773	—	—	58	42	—	1524	—	—	54	46	—	1314	—	—	50	50	—	1125	—	—	45	55	—
		75	—	—	—	—	—	—	—	—	—	—	—	—	1354	—	—	49	38	13	1175	—	—	44	37	19
		87	2063	—	47	53	—	—	1764	—	44	55	—	—	1494	—	41	59	—	—	1265	—	39	61	—	—
		86	2093	—	46	43	11	—	1814	—	44	38	18	—	1574	—	42	34	24	—	1355	—	39	32	29	—
		98	2443	46	54	—	—	—	2074	45	55	—	—	—	1744	43	57	—	—	—	1465	41	59	—	—	—
		97	2503	46	34	20	—	—	2154	44	31	25	—	—	1854	42	29	29	—	—	1575	40	27	33	—	—
		96	—	—	—	—	—	—	—	—	—	—	—	—	1884	42	28	22	8	—	1625	40	26	22	12	—
	>3.3 ≤4.2	65	1433	—	—	—	73	27	1224	—	—	—	64	36	1045	—	—	—	57	43	896	—	—	—	52	48
		76	1733	—	—	57	43		1454	—	—	52	48	—	1215	—	—	46	54	—	1026	—	—	43	57	—

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																							
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$						$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$						$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$						$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$					
			L_{max} m	Sucker rod size mm					L_{max} m	Sucker rod size mm					L_{max} m	Sucker rod size mm					L_{max} m	Sucker rod size mm				
				29	25	22	19	16		29	25	22	19	16		29	25	22	19	16		29	25	22	19	16
56	>3.3 ≤4.2	75	—	—	—	—	—	—	1474	—	—	51	41	8	1255	—	—	46	37	17	1086	—	—	42	36	22
		87	2003	—	45	55	—	—	1664	—	43	57	—	—	1375	—	39	61	—	—	1146	—	37	63	—	—
		86	2043	—	45	42	13	—	1724	—	42	37	21	—	1455	—	39	34	27	—	1226	—	35	32	33	—
		98	2363	45	55	—	—	—	1944	43	57	—	—	—	1595	41	59	—	—	—	1316	38	62	—	—	—
		97	2433	44	34	22	—	—	2034	42	30	28	—	—	1695	40	28	32	—	—	1416	38	25	37	—	—
		96	—	—	—	—	—	—	2054	42	30	23	5	—	1754	30	28	22	11	—	1476	37	25	22	16	—
	>4.2 ≤5.0	65	1413	—	—	—	71	29	1194	—	—	—	62	38	1005	—	—	—	55	45	847	—	—	—	50	50
		76	1703	—	—	56	44	—	1414	—	—	50	50	—	1165	—	—	45	55	—	967	—	—	41	59	—
		75	—	—	—	—	—	—	1434	—	—	50	40	10	1215	—	—	45	37	18	1027	—	—	42	34	24
		87	1973	—	45	55	—	—	1614	—	41	59	—	—	1315	—	38	62	—	—	1077	—	35	65	—	—
		86	2013	—	45	41	14	—	1674	—	41	36	23	—	1395	—	38	33	29	—	1157	—	34	31	35	—
		98	2323	45	55	—	—	—	1884	42	58	—	—	—	1525	39	61	—	—	—	1237	37	63	—	—	—
		97	2393	44	33	23	—	—	1974	42	29	29	—	—	1625	39	27	34	—	—	1327	35	26	39	—	—
		96	—	—	—	—	—	—	1994	40	30	24	6	—	1665	38	26	23	13	—	1397	36	26	21	17	—
	>5.0 ≤6.0	65	1374	—	—	—	69	31	1135	—	—	—	60	40	936	—	—	—	53	47	778	—	—	—	48	52
		76	1654	—	—	55	45	—	1335	—	—	48	52	—	1086	—	—	44	56	—	888	—	—	40	60	—
		75	—	—	—	—	—	—	1365	—	—	48	40	12	1136	—	—	42	37	21	938	—	—	38	34	28

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																							
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$						$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$						$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$						$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$					
			$L_{\max}$ m	Sucker rod size mm					$L_{\max}$ m	Sucker rod size mm					$L_{\max}$ m	Sucker rod size mm					$L_{\max}$ m	Sucker rod size mm				
				29	25	22	19	16		29	25	22	19	16		29	25	22	19	16		29	25	22	19	16
56	>5.0 $\leqslant 6.0$	87	1914	—	44	56	—	—	1515	—	40	60	—	—	1216	—	36	63	—	—	978	—	34	66	—	—
		86	1954	—	44	40	16	—	1585	—	39	36	25	—	1286	—	35	32	33	—	1058	—	33	29	38	—
		98	2244	44	56	—	—	—	1765	41	59	—	—	—	1396	37	63	—	—	—	1108	35	65	—	—	—
		97	2324	44	32	24	—	—	1855	40	29	31	—	—	1486	36	26	38	—	—	1198	33	25	42	—	—
		96	—	—	—	—	—	—	1885	40	29	23	8	—	1546	37	25	23	15	—	1268	34	24	21	21	—
70	$\geqslant 1.6$ $\leqslant 2.7$	76	1363	—	—	72	28	—	1214	—	—	65	35	—	1084	—	—	60	40	—	955	—	—	54	46	—
		87	1613	—	58	42	—	—	1424	—	54	46	—	—	1254	—	49	51	—	—	1095	—	45	55	—	—
		86	—	—	—	—	—	—	1434	—	54	40	6	—	1284	—	50	38	12	—	1135	—	46	35	19	—
		98	1943	57	43	—	—	—	1704	55	45	—	—	—	1484	51	49	—	—	—	1295	47	53	—	—	—
		97	1953	57	38	5	—	—	1734	55	33	12	—	—	1534	51	31	18	—	—	1345	46	30	21	—	—
	>2.7 $\leqslant 3.3$	76	1343	—	—	71	29	—	1174	—	—	63	37	—	1025	—	—	56	44	—	905	—	—	51	49	—
		87	1583	—	56	44	—	—	1374	—	52	48	—	—	1185	—	48	52	—	—	1025	—	43	57	—	—
		86	—	—	—	—	—	—	1384	—	51	40	9	—	1215	—	47	37	16	—	1065	—	42	35	23	—
		98	1903	56	44	—	—	—	1634	52	48	—	—	—	1395	48	52	—	—	—	1195	44	56	—	—	—
		97	1913	55	38	7	—	—	1664	51	34	15	—	—	1445	49	30	21	—	—	1255	44	29	27	—	—
	>3.3 $\leqslant 4.2$	76	—	—	—	—	—	—	1124	—	—	59	41	—	965	—	—	52	48	—	836	—	—	48	52	—
		87	1543	—	55	45	—	—	1304	—	48	52	—	—	1105	—	43	57	—	—	946	—	41	59	—	—

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																			
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$						$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$						$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$						$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$					
			L_{max} m	Sucker rod size mm					L_{max} m	Sucker rod size mm					L_{max} m	Sucker rod size mm					L_{max} m	Sucker rod size mm				
				29	25	22	19	16		29	25	22	19	16		29	25	22	19	16		29	25	22	19	16
70	>3.3 ≤4.2	86	—	—	—	—	—	—	1324	—	48	40	12	—	1145	—	44	36	20	—	986	—	41	33	26	—
		98	1853	55	45	—	—	—	1554	50	50	—	—	—	1295	46	54	—	—	—	1086	41	59	—	—	—
		97	1873	54	37	9	—	—	1584	49	33	18	—	—	1355	45	30	25	—	—	1146	41	28	31	—	—
	>4.2 ≤5.0	76	1294	—	—	68	32	—	1094	—	—	57	43	—	926	—	—	50	50	—	797	—	—	46	54	—
		87	1524	—	55	45	—	—	1274	—	48	52	—	—	1066	—	43	57	—	—	897	—	39	61	—	—
		86	—	—	—	—	—	—	1294	—	47	39	14	—	1096	—	41	36	23	—	937	—	38	33	29	—
		98	1814	54	46	—	—	—	1504	49	51	—	—	—	1236	44	56	—	—	—	1207	40	60	—	—	—
		97	1834	53	37	10	—	—	1544	48	32	20	—	—	1296	44	29	27	—	—	1087	39	28	33	—	—
	>5.0 ≤6.0	76	1264	—	—	66	34	—	1045	—	—	55	45	—	867	—	—	47	53	—	729	—	—	43	57	—
		87	1484	—	54	46	—	—	1205	—	45	55	—	—	987	—	41	59	—	—	819	—	38	62	—	—
		86	—	—	—	—	—	—	1235	—	45	38	17	—	1027	—	40	35	25	—	859	—	36	33	31	—
		98	1774	53	47	—	—	—	1425	46	54	—	—	—	1147	42	58	—	—	—	939	39	61	—	—	—
		97	1794	52	36	12	—	—	1465	46	31	23	—	—	1207	42	28	30	—	—	999	38	26	36	—	—
83	≥1.6 ≤2.7	87	1294	—	68	32	—	—	1154	—	60	40	—	—	1025	—	54	46	—	—	916	—	50	50	—	—
		86	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	926	—	48	38	14	—
		98	1564	66	34	—	—	—	1394	62	38	—	—	—	1225	56	44	—	—	—	1076	52	48	—	—	—
		97	—	—	—	—	—	—	1394	60	35	5	—	—	1245	56	32	12	—	—	1116	52	30	18	—	—

Table B. 1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																							
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$						$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$						$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$						$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$					
			L_{max} m	Sucker rod size mm					L_{max} m	Sucker rod size mm					L_{max} m	Sucker rod size mm					L_{max} m	Sucker rod size mm				
				29	25	22	19	16		29	25	22	19	16		29	25	22	19	16		29	25	22	19	16
83	>2.7 $\leqslant 3.3$	87	1247	—	66	34	—	—	1115	—	58	42	—	—	967	—	52	48	—	—	857	—	46	54	—	—
		86	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	867	—	42	38	20	—
		98	1544	66	34	—	—	—	1335	58	42	—	—	—	1156	52	48	—	—	—	1007	49	51	—	—	—
		97	—	—	—	—	—	—	1345	58	35	7	—	—	1186	53	32	15	—	—	1047	49	30	21	—	—
	>3.3 $\leqslant 4.2$	87	1244	—	63	37	—	—	1075	—	56	44	—	—	917	—	48	52	—	—	798	—	44	56	—	—
		86	—	—	—	—	—	—	—	—	—	—	—	—	917	—	43	41	16	—	808	—	39	37	24	—
		98	1504	63	37	—	—	—	1275	55	45	—	—	—	1087	51	49	—	—	—	928	45	55	—	—	—
		97	—	—	—	—	—	—	1295	55	34	11	—	—	1117	49	32	19	—	—	968	45	30	25	—	—
	>4.2 $\leqslant 5.0$	87	1234	—	63	37	—	—	1045	—	53	47	—	—	887	—	46	54	—	—	760	—	42	58	—	—
		86	1234	—	63	37	0	—	1045	—	53	47	0	—	897	—	43	39	18	—	760	—	42	58	—	—
		98	1484	62	38	—	—	—	1245	54	46	—	—	—	1047	48	52	—	—	—	880	44	56	—	—	—
		97	—	—	—	—	—	—	1265	54	33	13	—	—	1077	48	31	21	—	—	920	43	29	28	—	—
	>5.0 $\leqslant 6.0$	87	1204	—	61	39	—	—	996	—	51	49	—	—	829	—	44	56	—	—	693	—	40	60	—	—
		98	1444	60	40	—	—	—	1186	53	47	—	—	—	969	45	55	—	—	—	803	42	58	—	—	—
		97	—	—	—	—	—	—	1206	51	33	16	—	—	1009	46	30	24	—	—	843	41	28	31	—	—
95	$\geqslant 1.6$ $\leqslant 2.7$	87	1084	—	76	24	—	—	974	—	65	35	—	—	875	—	58	42	—	—	786	—	50	50	—	—
		98	1314	74	26	—	—	—	1174	66	34	—	—	—	1045	60	40	—	—	—	936	55	45	—	—	—

Table B.1 (continued)

d_p mm	S m	Symbol of rod	Percentage of each stage of the tapered sucker rod string																							
			$2\text{min}^{-1} \leqslant n \leqslant 5\text{min}^{-1}$						$5\text{min}^{-1} < n \leqslant 8\text{min}^{-1}$						$8\text{min}^{-1} < n \leqslant 11\text{min}^{-1}$						$11\text{min}^{-1} < n \leqslant 15\text{min}^{-1}$					
			L_{max} m	Sucker rod size mm					L_{max} m	Sucker rod size mm					L_{max} m	Sucker rod size mm					L_{max} m	Sucker rod size mm				
				29	25	22	19	16		29	25	22	19	16		29	25	22	19	16		29	25	22	19	16
95	≥1.6 ≤2.7	97	—	—	—	—	—	—	—	—	—	—	—	—	1055	59	33	8	—	—	956	55	30	15	—	—
	>2.7 ≤3.3	87	1064	—	73	27	—	—	945	—	63	37	—	—	836	—	55	45	—	—	747	—	53	47	—	—
		98	1294	73	27	—	—	—	1135	64	36	—	—	—	996	57	43	—	—	—	877	52	48	—	—	—
		97	—	—	—	—	—	—	—	—	—	—	—	—	1016	57	33	10	—	—	897	51	31	18	—	—
	>3.3 ≤4.2	87	1044	—	70	30	—	—	915	—	61	39	—	—	797	—	54	46	—	—	698	—	46	54	—	—
		98	1274	72	28	—	—	—	1095	61	39	—	—	—	937	53	47	—	—	—	818	49	51	—	—	—
		97	—	—	—	—	—	—	—	—	—	—	—	—	957	53	32	15	—	—	838	48	31	21	—	—
	>4.2 ≤5.0	87	1034	—	69	31	—	—	895	—	58	42	—	—	777	—	51	49	—	—	670	—	45	55	—	—
		98	1254	70	30	—	—	—	1065	59	41	—	—	—	907	51	49	—	—	—	780	47	53	—	—	—
		97	—	—	—	—	—	—	1065	57	35	8	—	—	927	52	32	16	—	—	800	46	30	24	—	—
	>5.0 ≤6.0	87	1014	—	66	34	—	—	856	—	54	46	—	—	729	—	48	52	—	—	623	—	43	57	—	—
		98	1224	67	33	—	—	—	1016	56	44	—	—	—	849	48	52	—	—	—	713	44	56	—	—	—
		97	—	—	—	—	—	—	1036	57	33	10	—	—	869	48	32	20	—	—	723	38	33	29	—	—

Note 1: During tabulating the design of tapered sucker rod string (Table B.1), related parameters are set as follows:

$\mu_c = 1\text{m Pa} \cdot \text{s}$; $\rho_{wL} = 950\ \text{kg/m}^3$; $\delta = 0.1\ \text{mm}$; $n_k = 2$ 个; $D_{ps} = 300\ \text{m}$; $p_o = 1\ \text{MPa}$; $v = 4968\ \text{m/s}$; $E = 2.058 \times 10^{11}\ \text{Pa}$; $T = 794\ \text{MPa}$; $C = 0.85$; $SF = 0.9$。

Note 2: Assume that the tubing string is anchored during tabulating the design of tapered sucker rod string (Table B.1).

Annex C
(Informative)
Design procedure for tapered sucker rod string

C.1 Design procedure for sinker bar

C. 1. 1 Knowledge of D_p, S and n (regard D_p as L_{max} here) leads to determination of a proper tapered sucker rod string together with percentage of its every stage from Table B. 1 of Annex B.

C. 1. 2 Friction force between the barrel and the plunger of a subsurface pump is given by

$$F_2 = 0.94(d_p/\delta) - 140 \qquad (C.1)$$

C. 1. 3 Calculation of hydraulic resistance caused by fluid flowing through traveling valves:

C. 1. 3. 1 Reynolds number is given by

$$Re = 52.63nS\rho_{wL}d_p^2/(d_o\mu_o) \qquad (C.2)$$

C. 1. 3. 2 Calculation of flow coefficient:

Flow coefficient μ may be found from Fig. C. 1 or given by

$$\mu = 0.28 \quad (\text{for } Re \leqslant 3\times10^4) \qquad (C.3)$$

$$\mu = 0.37 - \ln Re - 1.38 \quad (\text{for } Re > 3\times10^4) \qquad (C.4)$$

C. 1. 3. 3 Hydraulic resistance of fluid flowing through traveling valves is given by

$$F_5 = \frac{1.5n_k}{729\mu^2} \times \frac{A_p^3(1 - A_o/A_p)}{A_o^2} \times (Sn)^2\rho_{wL} \qquad (C.5)$$

where

$$A_p = (\pi/4)d_p^2$$

$$A_o = (\pi/4)d_o^2$$

C. 1. 4 Buoyancy force acting on the bottom of the sucker rod string is given by

$$F_{br} = A_{r1}D_p\rho_{wL}g \qquad (C.6)$$

C. 1. 5 Total force acting on the bottom of the sucker rod string during downstroke is given by

$$P_w = F_2 + F_{br} + F_5 \qquad (C.7)$$

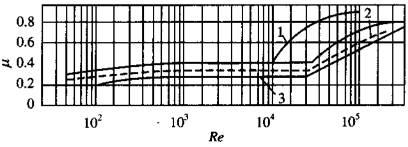
C. 1. 6 Length of sinker bar needed is given by

$$L_{sb} = \frac{P_w}{A_w\rho_r g} \qquad (C.8)$$

C. 1. 7 Considering variation in deviation angle, length of sinker bar may be given by

$$L_{sb} = \frac{0.98E'\gamma_L D_p}{W_j\cos\alpha_v(1 - 0.128\gamma_t)} \qquad (C.9)$$

Where E', sinker bar coefficient, may be found from Table C. 1.



1 — single valve, tank type; 2 — single valve, standard type; 3 — two valves

Fig. C. 1 Experimental chart

Table C. 1 Sinker bar coefficient

Pump diameter mm	Sinker bar coefficient cm^3	Pump diameter mm	Sinker bar coefficient cm^3
28	1. 94	57	3. 55
32	1. 94	64	3. 87
38	2. 58	70	4. 52
44	2. 90	83	7. 23
50	3. 23	95	9. 03

C.2 Procedure for approximately - equal - strength design of sucker rod string above sinker bar

C.2.1 Length calculation of every stage of sucker rod string.

Now that the tapered sucker rod string together with the percentage of each stage is known in Sec. C.1.1, the length of each stage is given by

$$L_{ri} = (D_p - L_{sb})\Delta i \qquad (C.10)$$

C.2.2 Length-weighted average cross-section area of tapered sucker rod string is given by

$$A_r = D_p / \left(\sum_{i=1}^{M} \frac{L_{ri}}{A_{ri}} + \frac{L_{sb}}{A_w}\right) \qquad (C.11)$$

C.2.3 Length - weighted average cross - section area of tubing string is given by

$$A_t = D_p / \sum_{j=1}^{Z} \frac{L_j}{A_{tj}} \qquad (C.12)$$

C.2.4 Weight of tapered sucker rod string in the fluid is given by

$$W_{rf} = \frac{\rho_r - \rho_{wL}}{\rho_r}\left(\sum_{i=1}^{M} L_{ri} q_i + P_w\right) \qquad (C.13)$$

C.2.5 Liquid column load acting on the pump plunger is given by

$$P_L = [(D_p - D_{ps})\rho_{wL} g + P_o]A_p \qquad (C.14)$$

C.2.6 Displacement that the hanger moves from start of the upstroke till the time when liquid column load fully acts on the pump plunger is given by

$$\lambda = \frac{P_L D_p}{E A_r} \quad \text{(for anchored tubing)} \qquad (C.15)$$

$$\lambda = \frac{P_L D_p}{E}\left(\frac{1}{A_r} + \frac{1}{A_t}\right) \quad \text{(for unanchored tubing)} \qquad (C.16)$$

C.2.7 Angle that the crank rotates from start of the upstroke till the time when liquid column load fully acts on the pump plunger is given by

$$\phi_c = \arccos(1 - 2\lambda / S) \qquad (C.17)$$

C.2.8 Deformation distribution coefficient is given by

$$\psi = A_t / (A_r + A_t) \quad \text{(for unanchored tubing)} \qquad (C.18)$$

$$\psi = 1 \quad \text{(for anchored tubing)} \qquad (C.19)$$

C.2.9 Maximum and minimum polished rod loads are given, respectively, by

$$P_{mh,max} = W_{rf} + P_L + \frac{EA_r}{v} \cdot \frac{\pi S n}{60} \cdot \left[\sin\left(\phi_c + \frac{\pi n D_p}{30 v}\right) - (1 - \psi)\sin\phi_c\right] \qquad (C.20)$$

$$P_{mh,min} = W_{rf} - C \cdot \frac{EA_r}{v} \cdot \frac{\pi S n}{60} \cdot \left[\sin\left(\phi_c + \frac{\pi n D_p}{30 v}\right) - (1 - \psi)\sin\phi_c\right] \qquad (C.21)$$

C.2.10 Check on the fatigue strength of tapered sucker rod string is conducted according to

$$\frac{P_{mh,max}}{A_{rJ}} \leqslant \left(\frac{T}{4} + 0.5625\frac{P_{mh,min}}{A_{rJ}}\right) SF \qquad (C.22)$$

If Eq. (C.22) is not satisfied, another tapered sucker rod string or higher grade rod should be chosen and calculated again according to the above procedure.

C.2.11 Peak reducer torque is given by

$$M_{ca,max} = 300S + 0.236S(P_{mh,max} - P_{mh,min}) \qquad (C.23)$$

C.3 Procedure for equal - strength design of sucker rod string located above sinker bar

C.3.1 Use of iterative method is made to design the tapered sucker rod string located above the sinker bar as follows.

C.3.2 Length - weighted average cross - section area of the part of the tapered sucker rod string which is located below the check point is given by

$$A_{sJ} = L_J / \left(\sum_{i=1}^{M} \frac{L_i}{A_{ri}} + \frac{L_{sb}}{A_w}\right) \qquad (C.24)$$

where

$$L_J = \sum_{i=1}^{M} L_{ri} + L_{sb}$$

C.3.3 Length - weighted average cross - section area of tubing string is given by

$$A_t = D_p / \sum_{j=1}^{Z} \frac{L_j}{A_{tj}} \qquad (C.25)$$

C.3.4 Weight in the fluid of tapered sucker rod string located below the check point is given by

$$W_{rfJ} = [(\rho_r - \rho_{wL})/\rho_r] \cdot \left(\sum_{i=1}^{M} L_{ri} q_i + P_w\right) \qquad (C.26)$$

C. 3. 5 Liquid column load acting on the pump plunger is given by Eq. (C. 14) .

C. 3. 6 Displacement that the check point moves from start of the upstroke till the time when liquid column load fully acts on the pump plunger is given by

$$\lambda_{\mathrm{J}}=\frac{P_{\mathrm{L}}L_{\mathrm{J}}}{EA_{\mathrm{sJ}}}\quad\text{(for anchored tubing)}\qquad(\mathrm{C.\,27})$$

$$\lambda_{\mathrm{J}}=\frac{P_{\mathrm{L}}}{E}\left(\frac{L_{\mathrm{J}}}{A_{\mathrm{sJ}}}+\frac{D_{\mathrm{p}}}{A_{\mathrm{t}}}\right)\quad\text{(for unanchored tubing)}\qquad(\mathrm{C.\,28})$$

C. 3. 7 Angle that crank rotates from start of the upstroke till the time when liquid column load fully acts on the pump plunger is given by

$$\phi_{\mathrm{cJ}}=\arccos(1-2\lambda_{\mathrm{J}}/S)\qquad(\mathrm{C.\,29})$$

C. 3. 8 Deformation distribution coefficient is given by

$$\psi_{\mathrm{J}}=A_{\mathrm{t}}/\ (A_{\mathrm{sJ}}+A_{\mathrm{t}})\quad\text{(for unanchored tubing)}\qquad(\mathrm{C.\,30})$$

$$\psi_{\mathrm{J}}=1\quad\text{(for anchored tubing)}\qquad(\mathrm{C.\,31})$$

C. 3. 9 Maximum and minium loads of the check point are given by

$$P_{\mathrm{mh,maxJ}}=W_{\mathrm{rfJ}}+P_{\mathrm{L}}+\frac{EA_{\mathrm{sJ}}}{v}\cdot\frac{L_{\mathrm{J}}}{D_{\mathrm{p}}}\cdot\frac{\pi Sn}{60}\cdot\left[\sin\left(\phi_{\mathrm{cJ}}+\frac{\pi nL_{\mathrm{J}}}{30v}\right)-(1-\psi_{\mathrm{J}})\sin\phi_{\mathrm{cJ}}\right]\qquad(\mathrm{C.\,32})$$

$$P_{\mathrm{mh,minJ}}=W_{\mathrm{rfJ}}-C\cdot\frac{EA_{\mathrm{sJ}}}{v}\cdot\frac{L_{\mathrm{J}}}{D_{\mathrm{p}}}\cdot\frac{\pi Sn}{60}\cdot\left[\sin\left(\phi_{\mathrm{cJ}}+\frac{\pi nL_{\mathrm{J}}}{30v}\right)-(1-\psi_{\mathrm{J}})\sin\phi_{\mathrm{cJ}}\right]\qquad(\mathrm{C.\,33})$$

C. 3. 10 Check on the fatigue strength of tapered sucker rod string is conducted according to Eq. (C. 22) .

C. 3. 11 If Eq. (C. 22) is not satisfied, increase the size of sucker rod to next stage of the tapered sucker rod string and follow C. 3. 2 ~ C. 3. 10 again.

C. 3. 12 When the size of sucker rod is increased to that of the last stage of the tapered sucker rod string, the ultimate pump - setting depth $L_{\max}$ of the tapered sucker rod string is obtained.

C. 3. 13 Comparison of D_{p} with $L_{\max}$

If $D_{\mathrm{p}}>L_{\max}$, choose another tapered sucker rod string or a higher grade rod ; if $D_{\mathrm{p}}<L_{\max}$, choose another tapered sucker rod string or a lower grade rod or reduce the SF value. Then repeat C. 3. 1~C. 3. 11 until $D_{\mathrm{p}}=L_{\max}$, thereby determining the sucker rod string meeting the needs of the well conditions.

C. 3. 14 Peak reducer torque is given by Eq. (C. 23) .

C. 4 Design procedure for design of sucker rod string located above sinker bar for use in deviated wells

Assuming that the whole hole axis is composed of circular curves of varying radius of curvature (as shown in Fig. C. 2), which are the sections between two consecutive survey points of hole deviation, and the curvature radii of whose projections on a vertical and a horizontal plane are R_i and r_i (here $i=0,\ 1,\ 2,\ 3,\ \cdots,\ n$ with the survey point of borehole deviation corresponding to the top of the pump plunger as the starting point), calculate the load of the top of each section P_i, which is P_{i-1} in the calculation of next section, until the maximum and the minimum polished rod loads are obtained. In the case of a tapered sucker rod string, maximum stress $\sigma_{\mathrm{r,max}}$ and minimum stress $\sigma_{\mathrm{r,min}}$ of the top of each stage should be checked to ensure $\sigma_{\mathrm{r,max}}<\sigma_{\mathrm{rp,max}}$, and if necessary, its stage lengths are adjusted.

C. 4. 1 Compressive force acting on the internal wall of tubing by unit length of sucker rod at hole section i is given by

$$N_i=\sqrt{\left[p_{i-1}\cdot\frac{1}{R_i}-(1\pm m_n)W_n\sin\alpha_{\mathrm{v}i}\right]^2+\left(p_{i-1}\cdot\frac{1}{r_i}\sin^2\alpha_{\mathrm{v}i}\right)^2}\qquad(\mathrm{C.\,34})$$

Where

$$\frac{1}{R_i}=\frac{\alpha_{i-1}-\alpha_i}{57.3\mid\Delta L_i\mid}$$

$$\frac{1}{r_i}=\frac{\phi_{\mathrm{H}i-1}-\phi_{\mathrm{H}i}}{57.3\mid\Delta L_i\mid\sin\alpha_{\mathrm{v}i}}$$

In Eq. (C. 34), the plus sign should be applied in calculations referring to the upstroke while the minus sign in calculations referring to the downstroke.

C. 4. 2 Friction between sucker rod and tubing at hole section i is given by

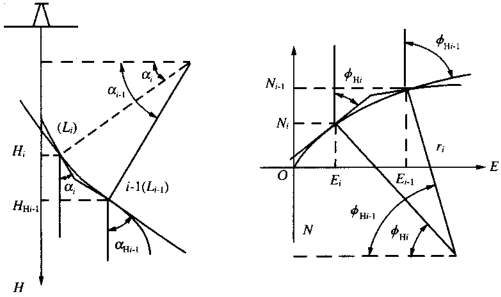


Fig. C. 2 Projections of hole trajectory on vertical and horizontal planes

$$F_{1i} = fN_i \mid \Delta L_i \mid \qquad (C.35)$$

where

$$\Delta L_i = L_i - L_{i-1}$$

C. 4. 3 On the downstroke, friction between sucker rod and well fluid at hole section i is given by

$$p_{Lri} = 3 \times 10^{-4} Sn\mu_o \mid \Delta L_i \mid \cdot \left[\frac{K_{tr}^2 - 1}{(K_{tr}^2 + 1)\ln K_{tr} - (K_{tr}^2 - 1)} \right] \qquad (C.36)$$

where

$$K_{ti} = D_{ti}/d_{ri}$$

C. 4. 4 On the upstroke, friction force between sucker rod and well fluid at hole section i is given by

$$p_{Lti} = \frac{p_{Lri}}{1.3} \qquad (C.37)$$

C. 4. 5 Friction between barrel and plunger of the pump is given by Eq. (C. 1) .

C. 4. 6 Liquid column load acting on the pump plunger is given by Eq. (C. 14) .

C. 4. 7 Maximum and minimum sucker rod loads of the top of hole section i are given by

$$P_{mh,max} = P_{ui-1} + (1 + m_a)\xi W_{ri}\cos\alpha_{vi} \cdot \mid \Delta L_i \mid + \xi P_w + P_{ti} + P_{Lti} \qquad (C.38)$$

$$P_{mh,min} = P_{di-1} + (1 + m_a)\xi W_{ri}\cos\alpha_{vi} \cdot \mid \Delta L_i \mid + \xi P_w - P_{wi} - P_{Lti} \qquad (C.39)$$

where

$$m_a = \frac{Sn^2}{1790}$$

C. 4. 8 Fatigue strength is checked by Eq. (C. 22) . If Eq. (C. 22) is not satisfied, another tapered sucker rod string or higher grade rod should be chosen and calculated again according to the above procedure.

C. 4. 9 Peak reducer torque is given by Eq. (C. 23) .

C. 5 Example of design of tapered sucker rod string

Design the sucker rod string in a pumping well, given the following data:

Diameter of subsurface pump, mm	44
Pump clearance	I
Number of traveling valves	2
Pump setting depth, m	1800
Depth to flowing fluid level in casing, m	1400
Tubing-head pressure, MPa	0. 7
Salinity of well fluid	low
Dynamic viscosity of well fluid, mPa • s	10
Density of well fluid, kg/m^3	850
Length of stroke, m	6
Pumping speed, min^{-1}	4
Whether is tubing anchored	NO

C. 5. 1 Initial grade selection of sucker rod: Because of low fluid salinity and heavy load of the well and, Grade D rod will be tried first, whose minimum tensile strength $T = 793$ MPa, Let $SF = 0.9$.

C. 5. 2 Initial selection of tapered sucker rod string:

According to the given data $d_p = 44$ mm, $S = 6$ m, $n = 4$ min^{-1} and $D_p = 1800$ m, it is found from Table B. 1 that the tapered sucker rod string symbol 65 is suitable for use in the well. It is 1843m in maximum pump setting depth L_{max}, and is made up of 58% of 19mm rod and 42% of 16mm rod.

C. 5. 3 Calculation of barrel - plunger friction:

$$F_2 = 0.94(d_p/\delta) - 140 = 1041(\mathrm{N})$$

C. 5. 4 Calculation of Reynolds number:

$$Re = 52.63 nS\rho_{wL} d_p^2/(d_o \mu_o) = 9448$$

C. 5. 5 Calculation of flow coefficient:

For Re $= 9448 < 3 \times 10^4$, it is obtained according to Eq. (C. 3) that $\mu = 0.28$.

C. 5. 6 Calculation of hydraulic resistance caused by fluid flowing through traveling valves:

$$F_5 = \frac{1.5 n_k}{729\mu^2} \cdot \frac{A_p^3(1 - A_o/A_p)}{A_o^2} \cdot (Sn)^2 \rho_{wL}$$
$$= 780(\mathrm{N})$$

C. 5. 7 Calculation of buoyancy force acting on the bottom of sucker rod string:

$$F_{br} = A_{r1} D_p \rho_{wL} g = 3014(\mathrm{N})$$

C. 5. 8 Calculation of total resistance acting on the bottom of sucker rod string during downstroke:

$$P_w = F_2 + F_{br} + F_5 = 4835(\mathrm{N})$$

C. 5. 9 Calculation of length of sinker bar needed. Let the diameter of the sinker bar be 38mm, then

$$L_{sb} = P_w/(A_w \rho_r g) = 44(\mathrm{m})$$

C. 5. 10 Calculation of length of every rod size:

For 16mm rod, $L_{r1} = (D_p - L_{sb})\ \Delta i = (1800 - 44) \times 41\% = 738$ (m)

For 19mm rod, $L_{r2} = 1800 - 44 - 738 = 1018$ (m)

C. 5. 11 Calculation of length - weighted average cross - sectional area of sucker rod string

$$A_r = D_p / \left(\sum_{i=1}^{M} \frac{L_{ri}}{A_{ri}} + \frac{L_{sb}}{A_w} \right) = 0.000246(\mathrm{m}^2)$$

C. 5. 12 Calculation of length - weighted average cross - sectional area of tubing string:

According to length of every rod size calculated in Eq. (C. 10), single - size tubing string with an OD of 73mm is chosen, so

$$A_t = D_p / \sum_{j=1}^{Z} \frac{L_j}{A_{tj}} = 0.001165(\mathrm{m}^2)$$

C. 5. 13 Calculation of weight of sucker rod string in well fluid:

$$W_{rf} = \frac{\rho_r - \rho_{wL}}{\rho_r} \left(\sum_{i=1}^{M} L_{ri} q_i + p_w \right) = 37502(\mathrm{N})$$

C. 5. 14 Calculation of liquid column load:

$$P_L = [(D_p - D_{ps}) P_{wL} g + P_o] A_p = 16370(\mathrm{N})$$

C. 5. 15 Calculation of displacement of hanger at the end of primary deformation stage:

The tubing is not anchored, so

$$\lambda = \frac{P_L D_p}{E} \left(\frac{1}{A_r} + \frac{1}{A_t} \right) = 0.38(\mathrm{m})$$

C. 5. 16 Calculation of crank angle at the end of primary deformation stage:

$$\phi_c = \arccos(1 - 2\lambda/S) = 0.51(\mathrm{rad})$$

C. 5. 17 Calculation of deformation distribution coefficient:

The tubing is not anchored, so

$$\psi = A_t/(A_r + A_t) = 0.825$$

C. 5. 18 Calculation of maximum and minimum PRLs:

$$P_{mh,max} = W_{rf} + P_L + \frac{EA_r}{v} \cdot \frac{\pi Sn}{60}$$
$$\cdot \left[\sin\left(\phi_c + \frac{\pi n D_p}{30v} \right) - (1 - \psi)\sin\phi_c \right] = 60683(\mathrm{N})$$

$$P_{mh,min} = W_{rf} - C \cdot \frac{EA_r}{v} \cdot \frac{\pi Sn}{60}$$
$$\cdot \left[\sin\left(\phi_c + \frac{\pi n D_p}{30v} \right) - (1 - \psi)\sin\phi_c \right] = 30690(\mathrm{N})$$

C. 5. 19 Check on fatigue strength:

The left side of Eq. (C. 22):

$$\frac{P_{mh,max}}{A_{rJ}} = 214(\mathrm{MPa})$$

The right side of Eq. (C. 22):

$$\left(\frac{T}{4} + 0.5625 \frac{P_{mh,min}}{A_{rJ}} \right) SF = 233(\mathrm{MPa})$$

It is apparent from above that the sucker rod string is of enough strength.

Annex D

(Informative)

Operation design instruction of sucker rod pumping

D.1 Paper size of operation design instruction

Paper size of operation design instruction is 190mm×265mm，namely A4.

D.2 Format of operation design instruction

Format of operation design instruction (see Table D.1)

Table D.1 Operation design instruction of well ________

Operation purpose							
Static data	Specification and depth of casing	mm× m	Casing thickness	mm	Pro-duction data	Liquid production	t/d
	Perforated interval	m	Casing to bushing distance	m		Oil production	t/d
	Mid depth of oil zone	m	Artificial bottom of a well	m		Water cut	%
	Pumping unit		Depth of kickoff point	m		Flowing pressure	MPa
	Total horizontal displacement	m	Rate of over－all angle change	(°) /30m		Static pressure	MPa
	Maximum hole deviation	Interval，m	Maximum deviation angle	(°)		Date to measure static pressure	
Borehole condition and existing problems							
Pipe strings of original well							

Sketch map of string design					Operation requirements and cautions
Zone	Pipe string	Name	Depth m	Specification m	

Operation party		Designer		Primary Check	
Double check		Official of checkup and approval		Design date	

D. 3 Requirements of filling in operation design instruction

D. 3. 1 Fill in operation purpose column

The objective of the operation should be filled in this column. Comma is used to separate each item. If too many items can't be written down in a single row, another row should be used following the former row.

D. 3. 2 Fill in production data and status of original well strings

This column should be filled in on the basis of surveying oil wells. Status of original well strings must include last operating date, current and other string structure related to the operation, which lays a foundation for operator to prepare materials and plan specific process for the operation.

D. 3. 3 Fill in the column of string design sketch map

For pumping wells without water shut off, allocation or sand control treatments in some zones, these zones needn' t be marked, otherwise, sketch map of oil zones at the corresponding depth in the string graph should be drawn and zone code names and essential depth data should be marked.

In the column of strings graph, sketch map is drawn depending on the corresponding position of each arranged downhole tool, and one line is drawn from the bottom of each tool to the specification column on the right. The lines for tubing and rod could be put at any position in the same stage; the line for pump should be drawn at the end of the standing valve; and lines for other downhole tools should be drawn at the bottom. As to packer, its top depth of packing element should be marked. Nominal size is used for all the data in the specification column. In case of the precision of depth data being rigorously restricted, its precision should be marked. Otherwise, units of the data should be put zero.

D. 3. 4 Fill in the borehole condition and existing problems column

The borehole condition and oil well problems should be filled in this column, which needs to pay attention by operation section. For example: indicate the characteristics of casing deformation and the depth of the deformation point, or indicate what kind of fish dropped and the depth of the top of fish.

D. 3. 5 Fill in operation requirements and cautions column

Requirements of operation arrangement should be filled in the column. For example: indicate the running sequence of rods and value of shock isolation space.

D. 3. 6 Fill in static data column

Depth of kickoff point, total horizontal displacement, rate of over - all angle change, maximum borehole deviation and maximum deviation angle should be filled in for deflecting wells, otherwise, no need filling in these data for vertical wells.

Annex E
(Informative)
Operation summary of sucker rod pumping

E. 1 Paper size of operation summary

Single paper size of printed operation summary is 190mm×265mm, namely A4.

E. 2 Format of operation summary

Format of operation summary is seen Table E. 1.

Table E. 1 Operation summary of well ________

<table>
<tr><td colspan="5">Operation purpose:</td></tr>
<tr><td rowspan="4">Basic data</td><td>Specification and depth of casing</td><td>mm× m</td><td>Artificial bottom of a well</td><td>m</td></tr>
<tr><td>Perforated interval</td><td>m</td><td>Mid-depth of oil zone</td><td>m</td></tr>
<tr><td>Casing to bushing distance</td><td>m</td><td>Height of cross</td><td>m</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Operation data: From to</td></tr>
<tr><td>Sketch map of downhole strings</td><td colspan="4">Key data of downhole strings</td></tr>
<tr><td rowspan="6"></td><td>Pump diameter</td><td>mm</td><td>Pump setting depth</td><td>m</td></tr>
<tr><td>Pump manufacturer</td><td></td><td>Plug depth</td><td>m</td></tr>
<tr><td colspan="2">Specification of polish rod</td><td colspan="2">mm× m</td></tr>
<tr><td colspan="2">Specification and joints of tubing</td><td colspan="2">mm× joints</td></tr>
<tr><td colspan="2">Specification、joints and length of sucker rod</td><td colspan="2">mm× joints× m</td></tr>
<tr><td colspan="4"></td></tr>
</table>

Operation party: Editor: Assessor:

Table E. 2 Well ________ original well structure & well performance analysis

Original well structure diagram	Original well performance analysis

Operation party: Editor: Assessor:

Table E.3 Working procedure instruction

Working procedure	Completion date	Key data

Operation party: Editor: Assessor:

Table E.4 Well __________ trouble shooting

Trouble shooting:

Operation party: Editor: Assessor:

Table E. 5 Well ________ tubing record

Operation date: (dd/mm/yy)

Order No.	Length m	Accumulated length m	Order No.	Length m	Accumulated length m	Order No.	Length m	Accumulated length m
						Tubing size		
						Type		
						Inside caliper	Diameter	
							Length	
						Casing top spacing		
						Cross height		
						Tubing hanger		
						Rod pump	Length	
							I. D.	
							Setting depth	
						Accumulated length		
						Depth		
						Working barrel		
							Depth	
							I. D.	
						Measurer		
						Calculater		
						Examiner		

Operation party: Editor: Assessor:

表 E. 6 Well ________ sucker rod record

Operation date: (dd/mm/yy)

Order No.	Length m	Accumulated length m	Order No.	Length m	Accumulated length m	Order No.	Length m	Accumulated length m
						Polished rod size		
						First - stage rod		
						Second - stage rod		
						Third - stage rod		
						Plunger		
							Length	
							O. D.	
						Accumulated length		
						Measurer		
						Calculater		
						Examiner		

Operation party:

Manager:

E. 3 Requirements in filling in operation summary

E. 3. 1 Original well performance analysis column

The downhole string and well bore status should be applied in this item, eg. The back off string or any other special tools, or casing deformation should be applied.

E. 3. 2 Trouble - shooting column

The problems should be applied in this item, including rod - tubing wearing status, description of tools, well bore status, and any treatments in operation.