IEEE Standards

IEEE Std 1019™-2004
(Revision of
IEEE Std 1019-1991)

1019™

IEEE Recommended Practice for Specifying Electric Submersible Pump Cable—Polypropylene Insulation

IEEE Industry Applications Society

Sponsored by the
Petroleum and Chemical Industry Committee

IEEE

3 Park Avenue, New York, NY 10016-5997, USA

13 April 2005

Print: SH95252
PDF: SS95252

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS

Not for Resale

--`,,`,,`,,,-`-`,,`,,`,`,,`---
and Electronics Engineers, Inc.
IEEE
itted without license from IHS
Not for Resale

Recognized as an
American National Standard (ANSI)

IEEE Std 1019™-2004
(Revision of
IEEE Std 1019-1991)

IEEE Recommended Practice for Specifying Electric Submersible Pump Cable—Polypropylene Insulation

Sponsored by

Petroleum and Chemical Industry Committee
of the
IEEE Industry Applications Society

Approved 1 February 2005

American National Standards Institute

Approved 23 September 2004

IEEE-SA Standards Board

Abstract: Minimum requirements for the construction, manufacturing, purchasing, and application of electric submersible pump cable are presented. The cable is round or flat, with polypropylene rubber insulation, nitrile jacket, and armor. These cables are for voltages not exceeding 3 kV or 5 kV (phase to phase) and conductor temperatures not exceeding 96 ºC (205 ºF) for nitrile or a maximum of –10 ºC (14 ºF). Conductors, insulation, assembly and jacket, armor, requirements for testing by the manufacturer, and cable ampacity are covered.
Keywords: ampacity ratings, assembly, cable construction, cable testing, field testing, submersible pump cable, testing

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2005 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 13 April 2005. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by the Institute of Electrical and Electronics Engineers, Incorporated.

Print: ISBN 0-7381-4081-3 SH95252
PDF: ISBN 0-7381-4082-1 SS95252

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

--`,,```,,,-`-`,,`,,`,`,,`---

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS

Not for Resale

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information contained in its standards.

Use of an IEEE Standard is wholly voluntary. The IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEEE Standard document.

The IEEE does not warrant or represent the accuracy or content of the material contained herein, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEEE Standards documents are supplied "**AS IS**."

The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

In publishing and making this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position, explanation, or interpretation of the IEEE.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board

445 Hoes Lane

Piscataway, NJ 08854

USA

NOTE-Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Introduction

This introduction is not part of IEEE Std 1019-2004, IEEE Recommended Practice for Specifying Electric Submersible Pump Cable—Polypropylene Insulation.

This recommended practice, under the jurisdiction of the Petroleum and Chemical Industry Committee of the IEEE Industry Applications Society, presents the minimum requirements for the construction, manufacturing, purchasing, and application of electric submersible pump cable. The configuration of the cable is either round or flat, with polypropylene insulation, nitrile jacket, and armor.

Anyone desiring to use this recommended practice may do so. It is presented as minimum criteria for construction of this class of submersible cable. It is not intended to restrict innovation or to limit development of improvements in cable design. Every effort has been made to assure the accuracy and reliability of the data contained herein; however, the committee makes no representation, warranty, or guarantee in connection with the publication of this specification and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use; for any violation of any federal, state, or municipal regulation with which it may conflict; or for the infringement of any patent resulting from the use of this recommended practice.

Notice to users

Errata

Errata, if any, for this and all other standards can be accessed at the following URL: http://standards.ieee.org/reading/ieee/updates/errata/index.html. Users are encouraged to check this URL for errata periodically.

Interpretations

Current interpretations can be accessed at the following URL: http://standards.ieee.org/reading/ieee/interp/index.html.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents or patent applications for which a license may be required to implement an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Participants

The following is a list of participants in the Downhole Working Group of the Petroleum and Chemical Industry Committee.

Marcus O. Durham, *Chair*
Thomson H. Wallace, *Secretary*

David Anderson
Gordon Baker
Lester Gagan
Robert Lannom
Howard Oswald
John Patterson
Rodney Story

The following members of the individual balloting committee voted on this recommended practice. Balloters may have voted for approval, disapproval, or abstention.

Russell E. Adams
J. K. Armintor
S. P. Axe
David C. Azbill
Iraj Boroumand
R. Bried
D. G. Broussard
M. M. Cameron
W. F. Casper
James M. Daly
Stephen M. Dillard
Gary Donner
Richard Doughty
Joseph S. Dudor
Marcus O. Durham
J. B. Dwyer
H. B. Dygert
C. J. Erickson
E. J. Fagan
R. W. Gallant
S. W. Hagemoen
J. D. Hill
F. P. Hogan
Richard H. Hulett
John Hus
Robert M. Jackson
Ben Johnson
M. Johnson
John H. Kassebaum
P. M. Kinney
J. C. Lacour
W. H. Levers
Clark R. Lockerd
B. W. McCarty
Bob McDaniel
Paul W. Myers
R. L. Nailen
R. A. Neil
J. P. Nelson
J. B. Overmeyer
T. P. Pearson
B. M. Polkinghorn
J. P. Propst
Milton H. Ramsey
Quentin Reynolds
S. W. Shannon
P. J. Skobel
A. W. Smith
T. B. Smith
H. R. Stewart
E. B. Turner
Don Vardeman
Albert E. Whiteside
Barrt Wusenab
J. R. Zahn
Peter Zoto

When the IEEE-SA Standards Board approved this recommended practice on 23 September 2004, it had the following membership:

Don Wright, *Chair*
Steve M. Mills, *Vice Chair*
Judith Gorman, *Secretary*

Chuck Adams
Stephen Berger
Mark D. Bowman
Joseph A. Bruder
Bob Davis
Roberto de Marca Boisson
Julian Forster*
Arnold M. Greenspan
Mark S. Halpin
Raymond Hapeman
Richard J. Holleman
Richard H. Hulett
Lowell G. Johnson
Joseph L. Koepfinger*
Hermann Koch
Thomas J. McGean
Daleep C. Mohla
Paul Nikolich
T. W. Olsen
Ronald C. Petersen
Gary S. Robinson
Frank Stone
Malcolm V. Thaden
Doug Topping
Joe D. Watson

*Member Emeritus

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

Satish K. Aggarwal, *NRC Representative*
Richard DeBlasio, *DOE Representative*
Alan Cookson, *NIST Representative*

Michael D. Fisher
IEEE Standards Project Editor

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Contents

1. Scope 1

2. Normative references 2

3. Conductors 2

3.1 Material 2
3.2 Construction 3
3.3 Conductivity 3

4. Insulation 3

4.1 Material 3
4.2 Construction 4
4.3 Gas blockage 5

5. Assembly and jacket 5

5.1 Material 5
5.2 Construction 6

6. Armor 6

6.1 Material 6
6.2 Construction 7

7. Manufacturers' electrical test requirements 7

7.1 Conductor testing 7
7.2 Electrical testing 7

8. Cable ampacity 11

8.1 Ampacity 11
8.2 Temperature 11
8.3 Safety factor 11
8.4 Conductor size 11
8.5 Economics 12

9. Tutorial information 12

9.1 Special terms 12
9.2 Application considerations 15

Annex A (informative) Cable designs and components 18

Annex B (informative) Figures 21

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

and Electronics Engineers, Inc.
IEEE
nitted without license from IHS
Not for Resale

IEEE Recommended Practice for Specifying Electric Submersible Pump Cable—Polypropylene Insulation

1. Scope

This recommended practice establishes requirements for three-conductor round-and-flat-type oil-well cable used in supplying three-phase ac electric power to submersible pump motors. The major cable components are copper conductors, polypropylene insulation, polymeric jacket, and galvanized armor. Cables meeting the requirements of this recommended practice should be rated for voltages not exceeding 3 kV or 5 kV (phase to phase).

Conductor operating temperatures for cables should not exceed 96 °C (205 °F). Use of cable above rated temperature can cause premature deterioration of the insulation. Low-temperature handling below –10 °C (14 °F) may cause cracking of the insulation or jacket.

Cable purchased under the recommendation of this recommended practice, unless otherwise specified herein, should meet the requirements of ASTM A90, ASTM B3, ASTM B8, ASTM B33, ASTM B189, ASTM B496, ASTM D412, ICEA S-19/NEMA WC 3, and ICEA S-61-402/NEMA WC 5, where applicable.[1]

This recommended practice recognizes the common practice of continuing to operate the pump's electrical system after a phase has faulted to ground and that some power distribution systems are even designed with one corner of the delta system grounded. The purpose of this recommended practice is not to condone or disapprove of such practice, but the user should be aware that such operation produces a higher than normal phase-to-ground voltage across the insulation/jacket dielectric of the two ungrounded conductors. Due to the disruption of the normally balanced three-phase field, such operation produces stresses through the insulation/jacket dielectric that shortens cable life. ICEA S-61-402/NEMA WC 5 recommends a 173% insulation level for grounded-phase operation, but this is often impractical for downhole oil-well cable; therefore, this specifying standard recommends insulation thickness based on a normal three-phase energized delta or wye system, with no phase grounded.

[1]Information on references can be found in Clause 2.

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

2. Normative references

The following referenced documents are indispensable for the application of this recommended practice. For dated references, only the edition cited applies. For undated references, the latest edition of the reference document (including any amendments or corrigenda) applies.

API RP 11S3, Recommended Practice for Electric Submersible Pump Installations, 2nd ed.[2]

API RP 11S4, Recommended Practice for Sizing and Selection of Electric Submersible Pump Installation, 3rd ed.

API RP 11S6, Recommended Practice for Testing of Electric Submersible Pump Cable Systems, 1st ed.

ASTM A90, Standard Test Method for Weight [Mass] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings.[3]

ASTM B3, Standard Specification for Soft or Annealed Copper Wire.

ASTM B8, Standard Specification for Concentric-Lay—Stranded Copper Conductors, Hard, Medium-Hard, or Soft.

ASTM B33, Standard Specification for Tinned Soft or Annealed Copper Wire for Electrical Purpose.

ASTM B189, Standard Specification for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes.

ASTM B496, Standard Specification for Compact Round Concentric-Lay—Stranded Copper Conductors.

ASTM D412, Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension.

ICEA S-19-81/NEMA WC 3, Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.[4]

ICEA S-61-402/NEMA WC 5, Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

IEEE Std 1017™, IEEE Recommended Practice for Field Testing Electric Submersible Pump Cable.[5]

3. Conductors

3.1 Material

Conductors should be annealed and coated in accordance with ASTM B33 for tin-coated conductors, or in accordance with ASTM B189 for lead or lead-alloy coated conductors.

[2]API publications are available from the Publications Section, American Petroleum Institute, 1200 L Street NW, Washington, DC 20005, USA (http://www.api.org/).

[3]ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).

[4]ICEA publications are available from ICEA, P.O. Box 20048, Minneapolis, MN 55420, USA (http://www.icea.org/).

[5]IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

--`,,`,,,,`-`-`,,`,,`,`,,`---

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS Not for Resale

3.2 Construction

Conductors should be solid or concentric-stranded as shown in Table 1 and Table 2. Concentric-stranded conductors should conform to ASTM B8, or when compact round conductors are used, they should conform to ASTM B496, with diameters nominally 92% of corresponding noncompact conductors. When stranded products are used, the interstices should be filled for gas blockage.

Table 1—Conductor characteristics (metric units)

Conductor	Conductor area	Nominal weight	Nominal diameter of conductor (mm)			Conductor resistance (Ω/km @ 25 °C)	
Trade size	(mm^2)	(kg/km)	Solid	Stranded 7 wire	Compact 7 wire	Plain copper	Tinned copper
10 mm^2	10.0	88.5	3.57	—	—	1.87	1.88
6 Awg	13.3	118.0	4.11	—	—	1.32	1.36
16 mm^2	16.0	140.0	4.48	—	—	1.17	1.18
4 Awg	21.1	188.0	5.19	—	—	0.830	0.856
4 Awg	21.1	188.0	—	5.89	5.41	0.846	0.882
25 mm^2	25.0	222.0	5.64	—	—	0.742	0.749
2 Awg	33.6	306.0	6.54	—	—	0.522	0.538
2 Awg	33.6	306.0	—	7.42	6.81	0.531	0.554
1 Awg	42.4	386.0	7.35	—	—	0.413	0.426
1 Awg	42.4	386.0	—	8.33	7.57	0.423	0.440
1/0 Awg	53.5	475.0	—	9.35	8.56	0.335	0.348
2/0 Awg	67.4	599.0	—	10.80	—	0.266	0.276

3.3 Conductivity

Conductors should have a direct current resistance at 25 °C (77 °F), not to exceed the values listed in Table 1 or Table 2.

4. Insulation

4.1 Material

Insulation should be a thermoplastic polypropylene meeting the properties shown in Table 3 when tested in accordance with ICEA S-61-402/NEMA WC 5, Section 6, except that pull rate should be 5.08 cm/min (2.0 in/min). The polypropylene should be copper stabilized.

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Table 2—Conductor characteristics (inch-pound units)

Conductor	Conductor area	Nominal weight	Nominal diameter of conductor (inches)			Conductor resistance (Ω/kft @ 77 °F)	
Trade size	(cmil)	(lb/kft)	Solid	Stranded 7 wire	Compact 7 wire	Plain copper	Tinned copper
10 mm^2	19 644	59.7	0.140	—	—	0.569	0.572
6 Awg	26 240	79.4	0.162	—	—	0.403	0.414
16 mm^2	31 109	95.6	0.178	—	—	0.357	0.360
4 Awg	41 740	126.0	0.204	—	—	0.253	0.261
4 Awg	41 740	126.0	—	0.232	0.213	0.258	0.263
25 mm^2	49 305	149.2	0.222	—	—	0.226	0.228
2 Awg	66 360	206.0	0.258	—	—	0.159	0.169
2 Awg	66 360	206.0	—	0.292	0.268	0.162	0.174
1 Awg	83 690	260.0	0.289	—	—	0.126	0.130
1 Awg	83 690	260.0	—	0.328	0.298	0.129	0.134
1/0 Awg	105 600	319.2	—	0.368	0.337	0.102	0.106
2/0 Awg	133 100	402.7	—	0.414	—	0.081	0.084

Table 3—Polypropylene properties

Physical requirements—unaged	
Tensile strength, minimum, MPa	20.7 (3000 psi)
Elongation at rupture, minimum, percent	250
Physical requirements—aged in air	
Oven at 121 °C (250 °F) for 1 week	
Tensile strength, minimum, percent of unaged value	75
Elongation at rupture, minimum, percent retention	75

4.2 Construction

The insulation should be extruded on the conductor. For 3 kV rated cable, average wall thickness should be 1.9 mm (0.075 in) or more, with a minimum wall thickness of 1.7 mm (0.068 in) at any point. For 5 kV rated cable, average wall thickness should be 2.3 mm (0.090 in) or more, with a minimum wall thickness of 2.1 mm (0.081 in) at any point.

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

4.3 Gas blockage

A 30 cm (12 in) specimen of insulated conductor removed from finished cable should be subjected to a 0.035 MPa (5 psi) differential air pressure for a period of 1 hour at 25 °C (77 ºF). The sample ends should be cut off flush with a fine-toothed saw blade, and one end of the sample should have a short section of clear flexible plastic tubing slid over the insulation to enable the specimen to be pressurized. The tubing should be attached in place with a small hose clamp [minimum width of binding collar = 6.4 mm (0.250 in)]. The clamp should be tightened with minimum torque to prevent leakage. The opposite end of the sample should be left submerged in water. No air bubbles should be detected at the submerged end of the cable during the test period.

5. Assembly and jacket

5.1 Material

The typical jacket is an oil-resistant thermosetting nitrile rubber meeting the properties shown in Table 4 when tested in accordance with ASTM D412.

An alternative jacket material used in high water cut, low-temperature applications is polyethylene. Cables using thermoplastic polyethylene have an upper conductor temperature limit of 80 °C (176 °F).

Table 4—Nitrile properties

Physical requirements—unaged	
Tensile strength, minimum, MPa	12.4 (1800 psi)
Elongation at rupture, minimum, percent	300
Physical requirements—aged in air	
Oven at 100 °C (212 °F) for 1 week	
Tensile strength, minimum, percent of unaged value	50
Elongation at rupture, minimum, percent retention	50
Physical requirements—aged in ASTM	
IRM 9002 oil at 121 °C (250 °F) for 18 hours	
Tensile strength, minimum, percent of unaged value	60
Elongation at rupture, minimum, percent retention	60

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

5.2 Construction

5.2.1 Round design

The three insulated conductors should be cabled around a centrally located filler that provides blockage. The conductors should be cabled with a left-hand lay having a maximum length of lay 35 times the individual conductor diameter.

A jacket should be extruded over a cable core consisting of three insulating conductors and central filler. The jacket should be extruded to fill all interstices. The average wall thickness should be 1.5 mm (0.060 in), and the minimum thickness at any point should be no less than 1.2 mm (0.048 in).

The outer surface of the jacket should have splines. These splines are not considered part of the specified wall; splines are provided for grip of the overlying armor. The jacket should separate cleanly from the underlying components.

5.2.2 Flat design

Each insulated conductor should be individually jacketed. Splines are not required on the jacket. An alternative design may have the three conductors laid parallel within a common encapsulated jacket. All interstices are filled with the jacketing material. The jacket of either design should separate cleanly from the underlying surface.

Additional constraining coverings may be applied over the insulation or jacket. They may be extruded, wrapped, and/or woven-type materials. Flat cable with a common encapsulated jacket or without individual constraining coverings may become oval during decompression from a gaseous environment.

For flat cable with additional constraining coverings, the average wall jacket thickness should be 1.3 mm (0.050 in). The minimum jacket thickness at any point should be no less than 1.0 mm (0.040 in).

For flat cable without additional constraining covering, the average jacket wall thickness should be 1.5 mm (0.060 in). The minimum jacket thickness at any point should be no less than 1.2 mm (0.048 in).

6. Armor

6.1 Material

The standard armor should be made from a galvanized steel strip.

6.1.1 Size

The thickness of the steel strip for round cable constructions, before galvanizing, should have a nominal thickness of 0.64 mm (0.025 in). The minimum wall thickness at any point should be no less than 0.56 mm (0.022 in). The thickness of the steel strip for flat cable constructions, before galvanizing, should have a nominal thickness of 0.51 mm (0.020 in). The minimum wall thickness at any point should be no less than 0.43 mm (0.017 in). The typical width of the steel strip is 12.7 mm (0.500 in) and should be no more than 19.1 mm (0.750 in) before forming.

6.1.2 Coating

The steel strip should be zinc-coated after slitting. The coating should be applied to all surfaces by the hot-dip galvanizing process.

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

6.1.3 Tensile strength and elongation

The zinc-coated strip should have a tensile strength of not less than 275 MPa (40 000 psi) and an elongation of not less than 10% in 25 cm (10 in). All tests should be performed in accordance with ICEA S-68-402/ NEMA WC 5 before application of the strip to the cable.

6.1.4 Weight of zinc coating

The weight of zinc coating should be determined before application of the strip to the cable. The strip should have a minimum coating weight of 110 g/m^2 (0.35 oz/ft^2) of exposed surface. The weight of the coating should be determined in accordance with the method described in ASTM A90. The zinc-coated strip should not exceed the bare-metal strip thickness by more than 20% at any point.

6.1.5 Adherence of coating

The zinc coating should remain adherent without flaking or spalling when tested in accordance with ICEA S-68-402/NEMA WC 5.

6.1.6 Armor for harsh environments

Thicker steel strip can be provided. Heavier Type II galvanizing may be used as per ASTM-A90. For extremely corrosive environments, stainless steel (316L) or other metal alloys is available.

6.2 Construction

6.2.1 Round cable

The armor strip should be applied over the cable core with sufficient tightness to compress the jacket splines. The strip should be helically applied and formed in such a manner as to be interlocked. The armor should withstand a seven times overall diameter bend radius without separation of adjacent turns.

6.2.2 Flat cable

The construction should consist of the three-phase conductors laid in parallel. The armor strip should be applied over the insulated conductors with sufficient tightness to fit snugly. The armor strip should be helically wrapped and formed in an overlapped manner. The assembly should withstand a bend that is seven times the major axis of the cable. The armor overlap should not open up between adjacent turns. The direction of bend should be in the normal direction of cable spooling.

7. Manufacturers' electrical test requirements

7.1 Conductor testing

Before application of any covering, conductors should be tested to meet the physical requirements of Clause 3.

7.2 Electrical testing

All submersible pump cables should be electrically tested by the manufacturer in accordance with this clause to determine compliance with these standards. Tests should be conducted on single-insulated conductors and on finished cable.

--`,,```,,,-`-`,,`,,`,`,,`---
Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

7.2.1 Electrical test methods

Electrical tests should be performed per ICEA S-61-402/NEMA WC 5, Section 3.6.2.

7.2.2 Single-insulated conductors before cabling

The insulated conductor should be immersed in water for a minimum of 6 hours, followed by a dc and/or an ac withstand test according to the values shown in Table 5. The duration of both tests should be 5 minutes.

Table 5—Test voltages for ESP cable[a]

Cable dating (kV rms) (phase-to-phase)	Factory test voltage (kV)	Acceptance test voltage[b] (kV)	Maintenance test voltage[c] (kV)
3	27	22	11
5	35	28	14

[a]All tests are dc, conductor to ground for 5 minutes.
[b]Acceptance test is 80% of factory test.
[c]Maintenance test is 40% of factory test.

7.2.3 Resistance

On completed cable, the conductor resistance test should be performed and should comply with Table 1 or Table 2.

7.2.4 DC withstand test

Finished armored cable should be tested in air by dc withstand test according to the values shown in Table 5. Each phase conductor should be tested individually. The armor, and the phase conductors not being tested at the time, should be grounded during the test. The negative polarity should be applied to the conductor under test. The test duration should be 5 minutes.

7.2.5 Conductance leakage readings

All power cables should be tested and meet the minimum test requirements for factory testing of conductance leakage at rated voltage listed in Table 5. The values are based on the bulk resistivity factor of 15 240 MΩ · km (50 000 MΩ · kft). Refer to API RP 11S6 for calculation method. See Table 6 and Table 7 for minimum conductance leakage readings.

7.2.6 Safety

After each test is completed, all conductors and armor must be shorted together and to ground. Maintain the ground for duration of at least twice the length of the previous test time to ensure that there is no residual charge.

7.2.7 Field testing

See IEEE Std 1017 for related information on testing submersible cable. Some interpretation guidelines are also included in that recommended practice.

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Table 6—Conductance leakage readings (metric units)

Values for 1.91 mm (75 mil) insulation thickness 3 kV EPDM					
Conductor	**Conductor diameter**	**Insulation minimum point**	**Calculated insulation diameter**	**IR value 1 km**	**DC leakage 1 km**
Trade size	**mm (in)**	**mm**	**mm**	**MΩ**	**μA/kV**
10 mm^2	3.56 (0.140)	1.73	7.01	4492	0.22
6 Awg	4.11 (0.162)	1.73	7.57	4034	0.25
16 mm^2	4.52 (0.178)	1.73	8.01	3757	0.27
4 Awg	5.18 (0.204)	1.73	8.66	3368	0.30
25 mm^2	6.55 (0.258)	1.73	10.01	2802	0.36
2 Awg	7.42 (0.292)	1.73	10.87	2531	0.40
1 Awg	8.43 (0.332)	1.73	11.89	2272	0.44
1/0 Awg	9.35 (0.368)	1.73	12.80	2079	0.48
2/0 Awg	10.52 (0.414)	1.73	14.00	1880	0.53
Values for 2.29 mm (90 mil) insulation thickness 5 kV EPDM					
Conductor	**Conductor diameter**	**Insulation minimum point**	**Calculated insulation diameter**	**IR value 1 km**	**DC leakage 1 km**
Trade size	**mm (in)**	**mm**	**mm**	**MΩ**	**μA/kV**
10 mm^2	3.56 (0.140)	2.06	7.01	5088	0.20
6 Awg	4.11 (0.162)	2.06	7.57	4587	0.22
16 mm^2	4.52 (0.178)	2.06	8.01	4283	0.23
4 Awg	5.18 (0.204)	2.06	8.66	3854	0.26
25 mm^2	6.55 (0.258)	2.06	10.01	3225	0.31
2 Awg	7.42 (0.292)	2.06	10.87	2921	0.34
1 Awg	8.43 (0.332)	2.06	11.89	2630	0.38
1/0 Awg	9.35 (0.368)	2.06	12.80	2412	0.41
2/0 Awg	10.52 (0.414)	2.06	14.00	2186	0.46

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Table 7—Conductance leakage readings (inch-pound units)

Values for 1.91 mm (75 mil) insulation thickness 3 kV EPDM					
Conductor	**Conductor diameter**	**Insulation minimum point**	**Calculated insulation diameter**	**IR value 1 kft**	**DC leakage 1 kft**
Trade size	**mm (in)**	**inches**	**inches**	**MΩ**	**μA/kV**
10 mm^2	3.56 (0.140)	0.068	0.276	14 739	0.07
6 Awg	4.11 (0.162)	0.068	0.298	13 235	0.08
16 mm^2	4.52 (0.178)	0.068	0.314	12 325	0.08
4 Awg	5.18 (0.204)	0.068	0.341	11 050	0.09
25 mm^2	6.55 (0.258)	0.068	0.398	9 194	0.11
2 Awg	7.42 (0.292)	0.068	0.428	8 303	0.12
1 Awg	8.43 (0.332)	0.068	0.468	7 455	0.13
1/0 Awg	9.35 (0.368)	0.068	0.504	6 823	0.15
2/0 Awg	10.52 (0.414)	0.068	0.550	6 168	0.16
Values for 2.29 mm (90 mil) insulation thickness 5 kV EPDM					
Conductor	**Conductor diameter**	**Insulation minimum point**	**Calculated insulation diameter**	**IR value 1 km**	**DC leakage 1 km**
Trade size	**mm (in)**	**inches**	**inches**	**MΩ**	**μA/kV**
10 mm^2	3.56 (0.140)	0.081	0.302	16 694	0.06
6 Awg	4.11 (0.162)	0.081	0.324	15 051	0.07
16 mm^2	4.52 (0.178)	0.081	0.340	14 053	0.07
4 Awg	5.18 (0.204)	0.081	0.367	12 646	0.08
25 mm^2	6.55 (0.258)	0.081	0.420	10 581	0.09
2 Awg	7.42 (0.292)	0.081	0.454	9 584	0.10
1 Awg	8.43 (0.332)	0.081	0.494	8629	0.12
1/0 Awg	9.35 (0.368)	0.081	0.530	7 794	0.13
2/0 Awg	10.52 (0.414)	0.081	0.576	7 171	0.14

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

8. Cable ampacity

8.1 Ampacity

Cable ampacity ratings are limited by these factors:

a) Ambient temperature
b) Liquid/gas environment
c) Heat rise due to resistance heating
d) Heat distortion properties of insulation
e) Ability to dissipate heat

8.2 Temperature

Conductor operating temperature as a function of well temperature and current flow is shown in Figure 1 to Figure 16.[6] These figures are based on Neher-McGrath calculations in an air environment. It is recommended that 96 °C (205 °F) be used as the maximum conductor operating temperature for polypropylene insulation with a nitrile jacket.

8.3 Safety factor

The Neher-McGrath calculations are based on the limit of performance for the material under ideal conditions. Because of real constraints in operating environments and the experience of the industry, it is necessary to restrict the temperature or current limits. The ampacity of the cable contains a safety factor that is 0.9 of the Neher-McGrath calculated value based on cable in air-filled buried pipe.

8.4 Conductor size

The conductor size depends on the length of the cable (D) in meters (feet), the current (I), the conductor resistivity (ρ), the ambient well temperature (T) in degrees Celsius (Fahrenheit), and the voltage drop (ΔV). The voltage drop is generally restricted to 5%.

The conductor resistivity is corrected for ac resistance and for temperature. The unit for resistivity is ohm square millimeter per meter (ohm circular-mil per foot). The basic value for bare copper resistivity is 0.017241 (10.371), and it is 0.017965 (10.810) for tinned copper.

$$\rho = \frac{0.017241 \times 1.02 \times (234.5 + T)}{254.5} \quad \text{METRIC UNITS}$$

$$\rho = \frac{10.371 \times 1.02 \times (234.5 + T)}{254.5} \quad \text{INCH-POUND UNITS}$$

The conductor area (A) is calculated from the following formula. The wire size is read from Table 1 or Table 2:

$$A = \frac{(\rho \times 1.732 \times D \times I)}{\Delta V}$$

[6]All figures cited in text can be found in Annex B.

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Example

Ambient temperature = 80 °C (1768 °F)

Distance = 1524 m (5000 ft)

Current = 60 A

Voltage = 2400 V phase to phase

Voltage drop = 5% = 120 V

$$p = \frac{0.017241 \times 1.02 \times (234.5 + 80)}{254.5} = 0.0217 \quad \text{METRIC UNITS}$$

$$A = \frac{(0.0217 \times 1.732 \times 1524 \times 60)}{120} = 28.64 \text{ mm}^2 \quad \text{METRIC UNITS}$$

$$p = \frac{10.371 \times 1.02 \times (234.5 + 80)}{254.5} = 13.07 \quad \text{INCH-POUND UNITS}$$

$$A = \frac{(13.07 \times 1.732 \times 5000 \times 60)}{120} = 56\ 593 \text{ cmils} \quad \text{INCH-POUND UNITS}$$

From Table 1 or Table 2, this would equate to a conductor trade size of #2 Awg (33.6 mm^2) or larger.

Use this wire size to check the cable temperature with the conductor temperature charts in Figure 1 through Figure 16. Plot the intersection of the conductor current and the maximum well temperature. The conductor temperature must be less than the rated temperature of the insulation and jacket. If it is greater, select a larger wire size.

8.5 Economics

Conductor ampacity ratings are not the only criteria for selecting a conductor size. For example, the economics of having greater power losses with a smaller conductor must be weighed against the cost of a larger size conductor. See 9.2.5.

9. Tutorial information

9.1 Special terms

cable tensile strength: The strength of the cable is basically the strength of the conductors. The other components of the cable can be eliminated as strength members. The cables are not designed to be used as a pulling device for components such as packers, seals, pumps, and motors.

The following example is provided for information about maximum breaking strength of the cable. This consideration is important when the cable must be used as a tension device. The cable will be destroyed.

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Example: 3/C #4 Awg solid copper

Copper tensile breaking strength = 344.7 MPa (50 000 psi)

Conductor diameter = 5.182 mm (0.204 in)

Conductor area = 21.1 mm^2 (0.0327 in^2)

Cable weight = 1.265 kg/m (0.85 lbs/ft)

Calculate the maximum force a single conductor can support in metric units (US):

Maximum force = 344.7 MPa × 21.1 mm^2 = 7273 N/conductor

METRIC UNITS

(Maximum force = 50 000 psi × 0.327 = 1635 lbs/conductor)

INCH-POUND UNITS

Assume the tension is equal on all three legs of the cable. The maximum pulling force that can be applied on the cable would be three times that of the single conductor:

Maximum force = 7273 N/conductor × 3 conductors = 21 820 N/cable

METRIC UNITS

(Maximum force = 1635 lbs/conductor × 3 conductors = 4905 lbs/cable)

INCH-POUND UNITS

Determine the length of cable whose weight alone exceeds this force:

Maximum length = 2182.5/1.265 = 1725 m METRIC UNITS

(Maximum length = 4905/0.85 = 5770 ft) INCH-POUND UNITS

compounds modulus: A relative measure of the force achieved at a given elongation of the material. It is normally recorded as a stress (megapascal or pound-force per square inch) at the given percent elongation. A lower modulus material has more of a tendency to give before breaking, that is, less resistance to expansion.

copper coating: Metal coatings such as lead or tin alloys are used on copper wires for many reasons. These reasons include annealing the copper during manufacture, preventing sulfur cured compounds from bonding to the copper, mitigating copper corrosion from sulfur (H_2S) compounds, and inhibiting propylene from decomposition.

elongation: The percent change in length for a given length.

hoop strength: It is a measure of the tangential resistance to elongation. As internal gas pressure pushes in a radial direction, it creates a tendency for the surface of the insulation and jacket to elongate and rupture in a tangential direction. The hoop strength resists this tendency and can be aided by additional wraps applied over the round components.

Copyright © 2005 IEEE. All rights reserved.

--`,,`,,,-`-`,,`,,`,`,,`---

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

polypropylene: A polymer of propylene. The homopolymer (one unit) of polypropylene is not used for wire and cable because it is brittle at temperatures above the freezing point. Copolymers must then be used for wire and cable applications. The copolymer consists of propylene and a polymerizable monomer such as ethylene.

shunt admittance: The reciprocal of impedance. Shunt admittance has the units siemens, S, or "mho." As used in this recommended practice, shunt admittance is a measure of leakage conductance to ground through the cable insulation.

stabilization: Polypropylene must be stabilized against certain metals because the polypropylene component of the plastic has a tendency to degrade in the presence of certain metal ions, e.g., copper and iron. Therefore, antioxidant stabilizers are used to inhibit material changes.

tensile strength: The stress (megapascal or pound-force per square inch) required to break the item.

tensile stress: The force exerted per unit area.

toughness factor: It is a measure of material performance under stress. It measures the ability of a material to withstand energy input over a unit of time. The toughness of a material equals one half the product of the material's tensile strength and elongation ratings. For the same toughness factor, a more brittle material will have greater tensile strength and less elongation, whereas a more gummy material will have less tensile strength and more elongation.

ultimate elongation: The percent change in length at rupture.

voltage stress: It may be thought of as the electrical pressure being applied to the insulation in an effort to burst through the material and short to ground. It could be thought of as analogous to water pressure in a pipe, where the higher the pressure, the harder it tries to burst through. For an electrical insulation material, the resistance to bursting through is known as the dielectric breakdown strength. It is usually expressed in terms of volts/millimeter (or volts/mil) required to puncture a sample of known thickness. For conventional cables, the voltage stress is normally maintained at less than 2165 V/mm (55 V/mil).

With electrical stress, the further away (outward) from the conductor one moves, the lower the stress becomes. Formulas used to calculate the electrical stress levels. They assume that the cable insulation is surrounded by a shield (i.e., lead sheath) or other adequate source of ground potential. The electrical stress level (S) may be calculated by the following formula:

$$S = \frac{E}{\left[2.303 \times r \times \ln\left(\frac{D_i}{d_c}\right)\right]} \quad \text{(V/mm) METRIC UNITS}$$

where

S is the stress in the insulation at radius r, volts/millimeter (volts/mil) (1 mil = 0.001 in = 0.0254 mm)

E is the phase-to-ground voltage, volts; for three phase systems, (phase-to-phase voltage)/1.732

D_i is the diameter over the insulation, millimeters (inches)

d_c is the diameter over the conductor, millimeters (inches)

r is the radial distance from the center of the conductor at which it is desired to calculate the electrical stress, millimeters (inches)

The maximum stress (S_{max}) on the insulation is at the conductor surface. In this case, r would be equal to $1/2 \times d_c$.

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

$$S_{max} = \frac{E}{\left[2.303 \times \frac{d_c}{2} \times \ln\left(\frac{D_i}{d_c}\right)\right]} \quad \text{(V/mm) METRIC UNITS}$$

$$S_{max} = \frac{E}{\left[0.0584 \times \frac{d_c}{2} \times \ln\left(\frac{D_i}{d_c}\right)\right]} \quad \text{(V/in) INCH-POUND UNITS}$$

The minimum stress (S_{min}) on the insulation is at the surface of the insulation. In this case, r would be equal to $1/2 \times D_i$.

$$S_{min} = \frac{E}{\left[2.303 \times \frac{D_i}{2} \times \ln\left(\frac{D_i}{d_c}\right)\right]} \quad \text{(V/mm) METRIC UNITS}$$

$$S_{min} = \frac{E}{\left[0.0584 \times \frac{D_i}{2} \times \ln\left(\frac{D_i}{d_c}\right)\right]} \quad \text{(V/in) INCH-POUND UNITS}$$

9.2 Application considerations

9.2.1 Installation

Cable installation requires running the cable over a sheave. The diameter of the sheave should be as large as possible, with a 137 cm (54 in) unit being the generally recommended size (see API RP 11S3). For round cable, the sheave surface should be concave to conform to the cable shape. Where flat cable is being predominantly run, the sheave should have a flat surface.

9.2.2 Pull rates

Gas has a very detrimental effect on cable systems. Polypropylene insulation is normally permeated to some extent by gas, which results in the insulation being softened by methane and other lower hydrocarbons, whereas carbon dioxide will initiate crazes leading to cracks and cable failure. In general, polypropylene will have a significantly shorter life expectancy in a CO_2 environment than other cable materials. The nitrile jacket readily absorbs gas.

Gas will permeate the materials and try to expand and contract according to temperature and pressure changes. Pressure will increase when the well is shut in. It will decrease when the well is producing. Therefore, gas in the jacket is alternately compressed and expanded. Moreover, during a pulling operation, the absorbed gas tries to rapidly expand, which potentially causes ruptures in the cable insulation and jacket.

Some manufacturers provide cable that is designed to rapidly expel gas as the pressure is decreased. Others attempt to minimize ruptures due to gas expansion by providing additional hoop strength. Methods such as lead sheaths or a tape and braid are used. The cable armor also helps control “blow outs” from rapid depressurization.

Although these approaches are beneficial, none can be fully effective under all conditions. If gas is found to be causing the cable to swell or rupture, the operator should consider reducing cable pulling rates. Typical rates vary from 305 m to 1200 m (1000 ft to 4000 ft) per hour. However, the “proper rate” is whatever works for a particular well. Keep in mind that significant cable damage from factors other than gas expansion can also occur from excessively high pull rates.

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

9.2.3 Chemical treatments

Most corrosion inhibitors have adverse effects on the nitrile jackets protecting the cable insulation. They include such things as softening or hardening of the nitrile jacket, which is reflected in changes in the jacket compounds modulus. Also, acid wash will cause the nitrile jacket to become brittle quickly. Inhibitors and well-treatment chemicals will also affect the cable armor. It is suggested that data from chemical tests on cable samples be reviewed before using a well treatment.

9.2.4 Balancing flat cable phase currents

Flat electric-motor cable has unbalanced series impedance, which causes current unbalance in electric submersible pump (ESP) motors. When flat cable is required, current unbalance can be minimized by rotating the cable connections to find the combination that produces the least unbalance.

However, it should be noted that currents entering the cable at the surface are not necessarily the same as the currents entering the submerged motor. High and unequal shunt admittance can produce a zero-sequence current, which causes a downhole current unbalance that is not reflected at the surface. Grounded-neutral, wye-connected power transformers will create that condition.

Common practice tries to maximize run life by using an ungrounded power source. Two faults must then occur before operation ceases. The ungrounded power source prevents flow of zero-sequence current, which thereby minimizes unbalance problems.

Even if the transformer neutral is not grounded, having one phase grounded downhole will also allow some zero-sequence current. Therefore, before rotating phases to balance currents, it is necessary to ensure that no phase conductor is grounded.

As the motor is connected to the end of the cable, it is not possible to measure individual phase insulation resistance directly. The motor effectively shorts the three phase conductors together. All three phases will have essentially the same resistance to ground readings.

On ungrounded secondary systems, the quality of each phase insulation system can be determined by measuring individual phase-to-ground voltages. If each voltage reading is within 10% of the overall average, then rotating the phases to achieve minimum current unbalance can be beneficial.

The three possible cable-to-motor-starter connections can be compared for minimum current unbalance. All three conductors must be rotated in sequence to avoid reversing the direction of motor rotation. The unbalanced series impedance of the cable can then be optimally connected to offset unbalances in input voltage and produce minimum unbalance in motor currents.

9.2.5 Economic ampacity

The economics of decreasing losses in the cable will provide incentive to increase the size of conductors. The economic ampacity of a cable is influenced as much by the cost of energy as by the cable material. The economic ampacity is the current at which the energy cost for the losses in the wire are equal to the incremental cost of the next larger wire size.

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

The equation for calculating the economic ampacity is shown here. The following equation calculates ampacity that will provide break-even economics for the specific conditions. If the operating current is higher than the current calculated by the equation, then a larger size conductor can be installed with a payout that is less than the time entered into the equation:

$$I = \left[\frac{\text{\$ per km change in wire cost} \times 1000\ \text{W/kWh}}{\text{resistance difference} \times \text{\$/kWh} \times \#\text{ph} \times \text{PO years} \times 24 \times 365}\right]$$

where

I	is the economic current
\$ per km change in wire cost	is the cost difference between two cables using different conductor sizes
resistance difference	is the difference in resistance between two conductor sizes at the well's bottom-hole temperature
\$/kWh	is the electrical power cost
#ph	is the number of phases (normally there are three)
PO years	is the number of years to see payout using the larger conductor

According to API RP 11S4, a maximum of 5% voltage drop over the entire length of the cable will provide a reasonable operating efficiency. In addition, using larger conductors will improve cable life by reducing internal heating caused by current flowing in the cable.

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Annex A

(informative)

Cable designs and components

A.1 Round cable normally used in wells with operating temperatures less than 80 ºC (176 ºF)—Figure 17[7]

1) Copper conductor
2) Insulation—polypropylene
3) Jacket—polyethylene—excellent abrasion resistance

A.2 Round cable normally used in wells with operating temperatures less than 96 ºC (205 ºF)—Figure 18

1) Copper conductor
2) Insulation—polypropylene
3) Jacket—oil-resistant nitrile rubber
4) Armor—standard 0.64 mm (0.025 in) galvanized steel

A.3 Flat cable normally used in wells with operating temperatures less than 96 ºC (205 ºF)—Figure 19

1) Copper conductor
2) Insulation—polypropylene
3) Jacket—oil-resistant nitrile rubber
4) Armor—standard 0.51 mm (0.020 in) galvanized steel

A.4 Flat cable normally used in wells with operating temperatures less than 96 ºC (205 ºF)—Figure 20

1) Copper conductor
2) Insulation—polypropylene
3) Jacket—oil-resistant nitrile rubber
4) Barrier layer, normally tape and braid
5) Armor—standard 0.51 mm (0.020 in) galvanized steel

[7]All figures cited in Annex A can be found in Annex B.

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

A.5 Round cable normally used in wells with operating temperatures less than 140 ºC (284 ºF)—Figure 21

1) Copper conductor
2) Insulation—EPDM
3) Jacket—oil-resistant nitrile rubber
4) Armor—standard 0.64 mm (0.025 in) galvanized steel

A.6 Round cable normally used in wells with operating temperatures less than 140 ºC (284 ºF)—Figure 22

1) Copper conductor
2) Insulation—EPDM
3) Optional, tape, braid, tape and braid, or extruded barrier
4) Jacket—oil-resistant nitrile rubber
5) Armor—standard 0.64 mm (0.025 in) galvanized steel

A.7 Flat cable normally used in wells with operating temperatures less than 140 ºC (284 ºF)—Figure 23

1) Copper conductor
2) Insulation—EPDM
3) Jacket—oil-resistant nitrile rubber
4) Barrier layer, normally tape and braid
5) Armor—standard 0.51 mm (0.020 in) galvanized steel

A.8 Round cable normally used in wells with operating temperatures less than 204 ºC (400 ºF)—Figure 21 and Figure 22

1) Copper conductor
2) Insulation—EPDM
3) Jacket—EPDM rubber
4) Armor—standard 0.64 mm (0.025 in) galvanized steel

A.9 Round cable normally used in wells with operating temperatures less than 204 ºC (400 ºF)—Figure 21 and Figure 22

1) Copper conductor
2) Insulation—EPDM
3) Optional, tape, braid, tape and braid, or extruded barrier
4) Jacket—EPDM rubber
5) Armor—standard 0.64 mm (0.025 in) galvanized steel

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

A.10 Flat cable normally used in wells with operating temperatures less than 204 ºC (400 ºF)—Figure 23

1) Copper conductor
2) Insulation—EPDM
3) Jacket—EPDM rubber
4) Barrier layer, normally tape and braid
5) Armor—standard 0.51 mm (0.020 in) galvanized steel

A.11 Flat cable lead sheath, for harsh environments and temperatures less than 204 ºC (400 ºF); for temperatures over 204 ºC (400 ºF), contact the manufacturer—Figure 24

1) Copper conductor
2) Insulation—EPDM
3) Jacket—Lead sheath
4) Bedding layer, can be braid or bedding tape
5) Armor—standard 0.51 mm (0.020 in) galvanized steel

--`,,`,,,,-`-`,,`,,`,`,,`---

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS Not for Resale

Annex B

(informative)

Figures

B.1 Conductor temperature charts

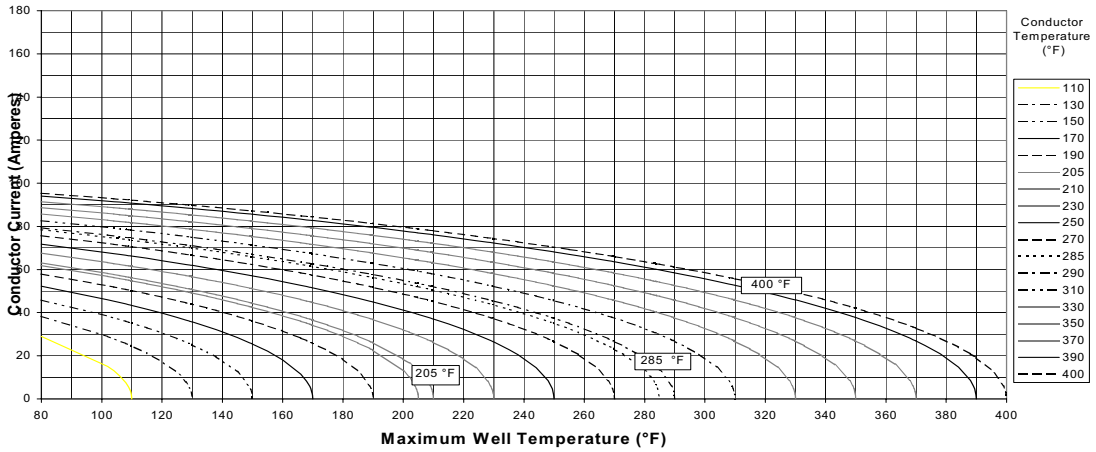


Figure 1—10 mm^2 solid flat pump cable conductor temperature chart

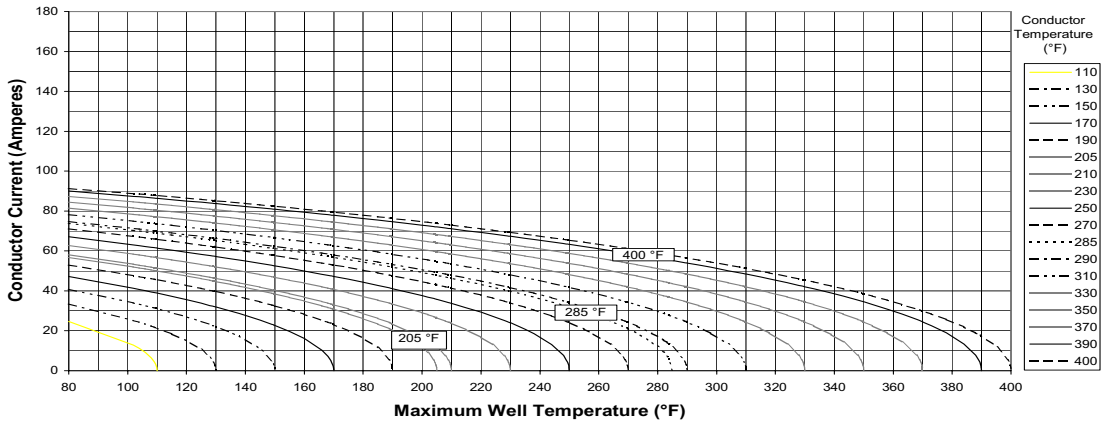


Figure 2—10 mm^2 solid round pump cable conductor temperature chart

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

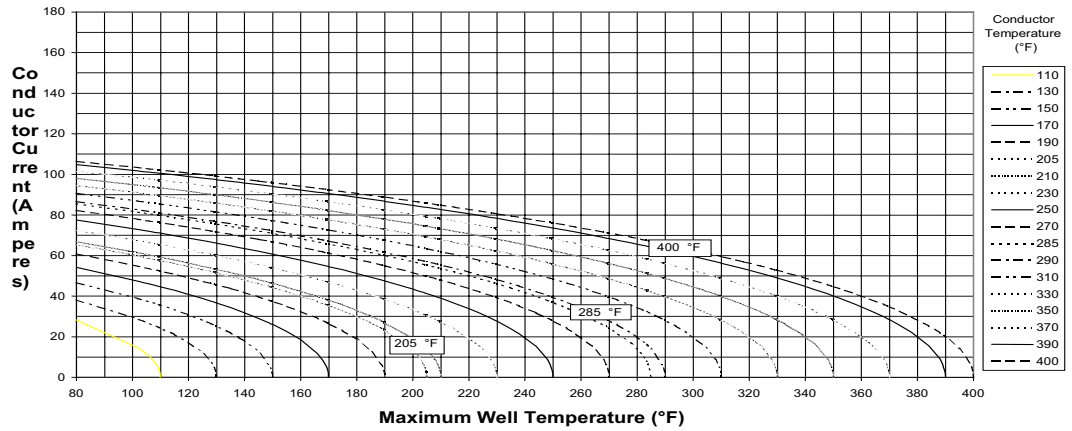


Figure 3—#6 Awg solid round pump cable conductor temperature chart

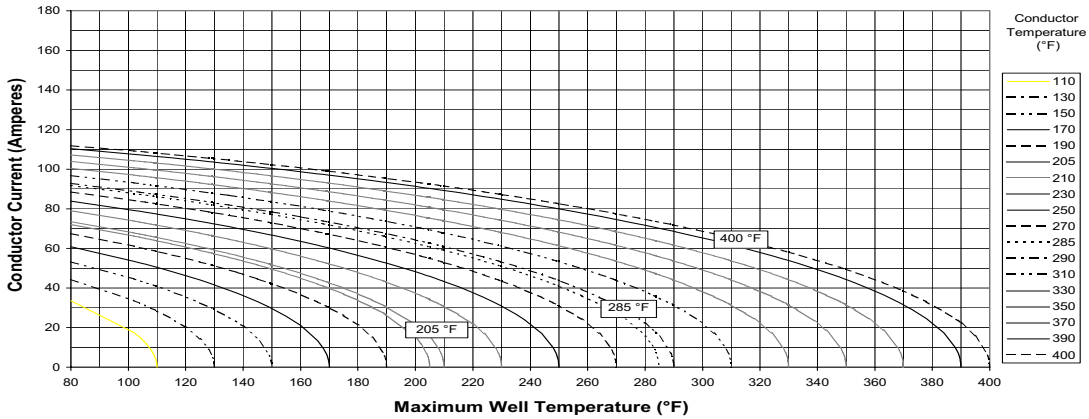


Figure 4—#6 Awg solid flat pump cable conductor temperature chart

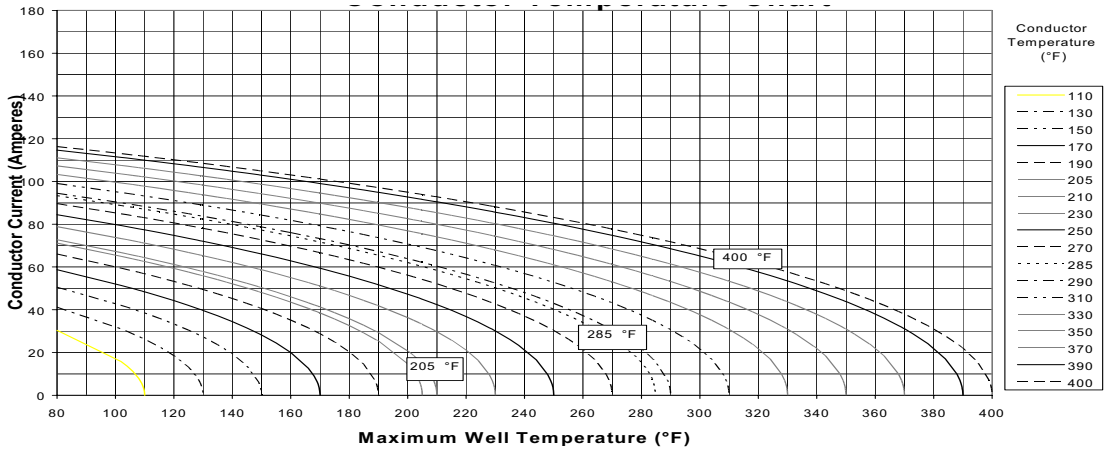


Figure 5—16 mm^2 solid round pump cable conductor temperature chart

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

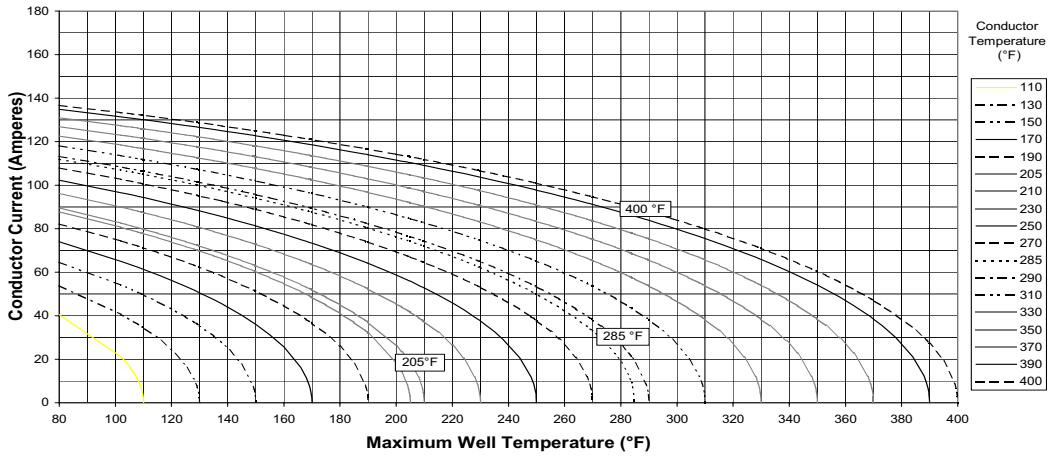


Figure 6—16 mm^2 solid flat pump cable conductor temperature chart

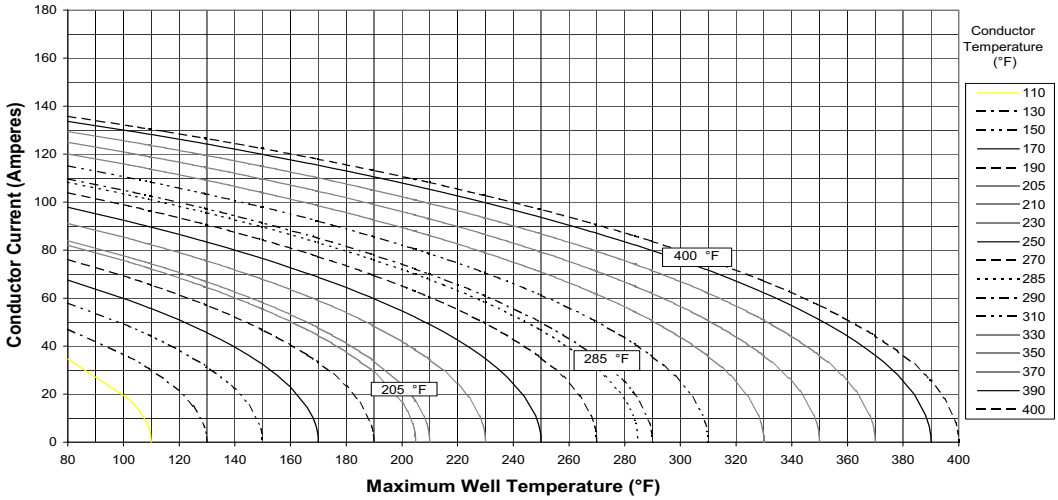


Figure 7—#4 Awg solid round pump cable conductor temperature chart

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

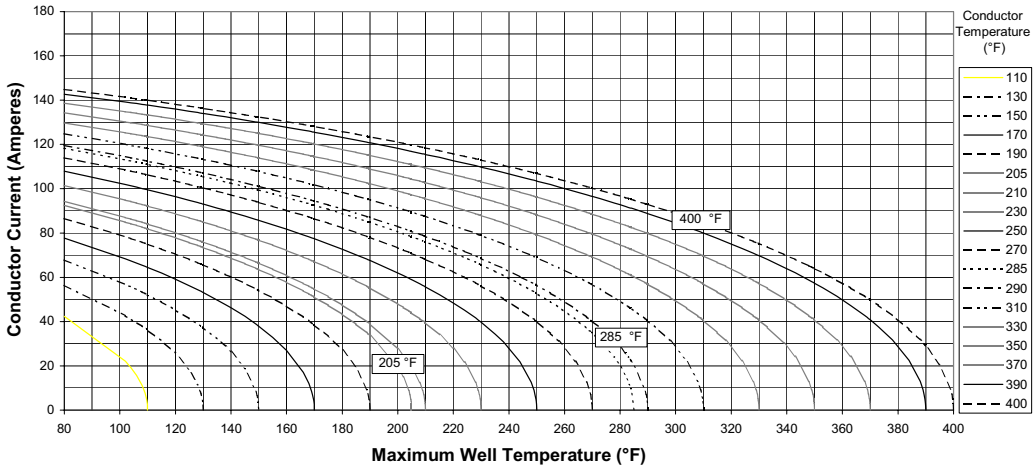


Figure 8—#4 Awg solid flat pump cable conductor temperature chart

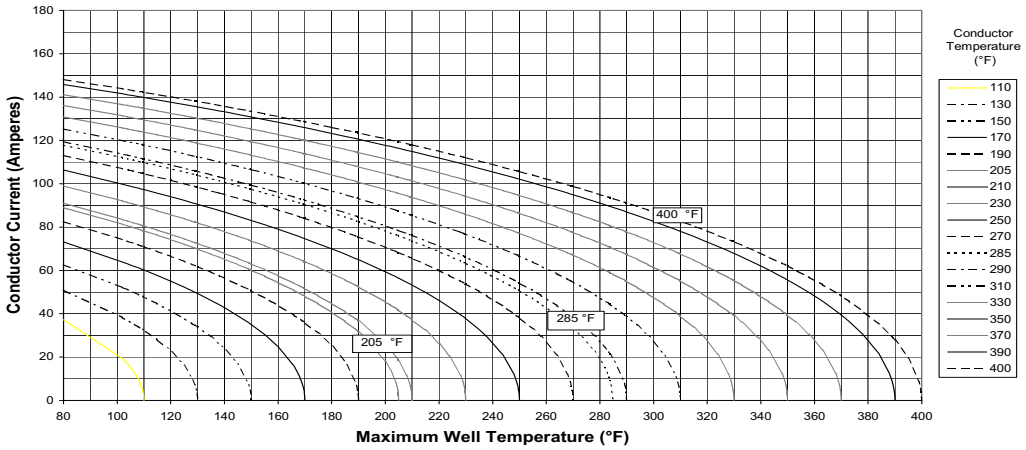


Figure 9—25 mm^2 solid round pump cable conductor temperature chart

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

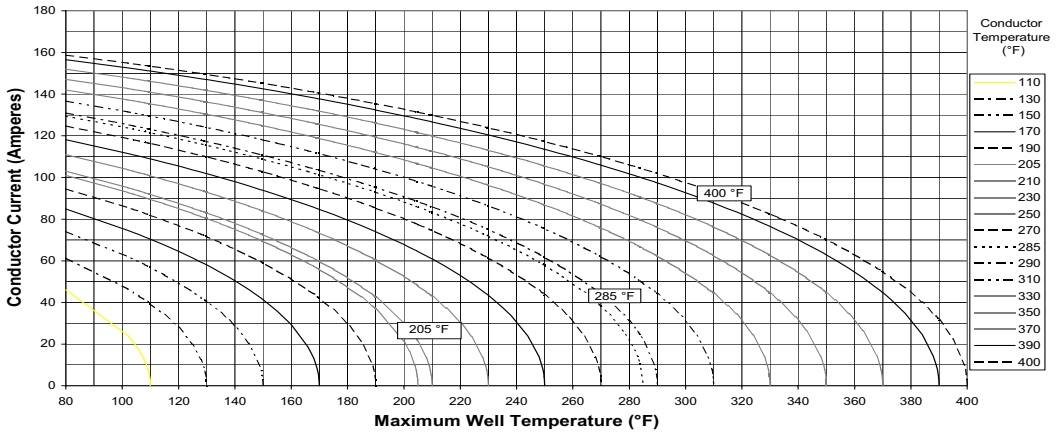


Figure 10—25 mm^2 solid round pump cable conductor temperature chart

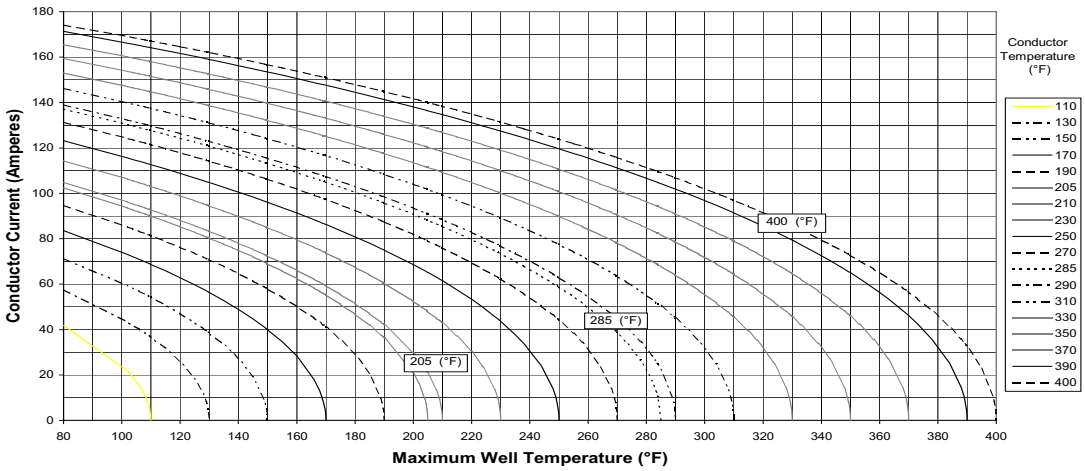


Figure 11—#2 Awg stranded round pump cable conductor temperature chart

--`,,`,,,`-`-`,,`,,`,`,,`---
Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

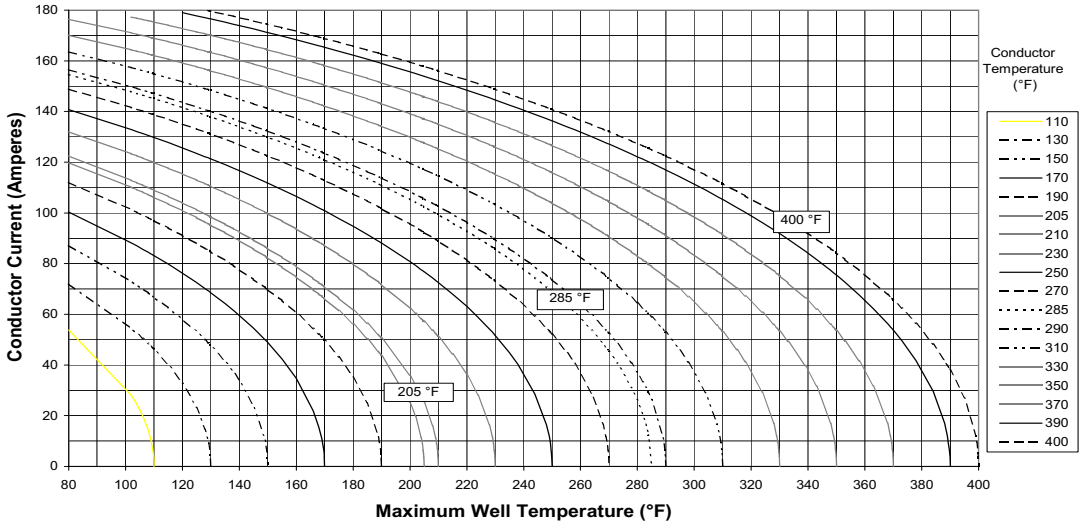


Figure 12—#2 Awg stranded flat pump cable conductor temperature chart

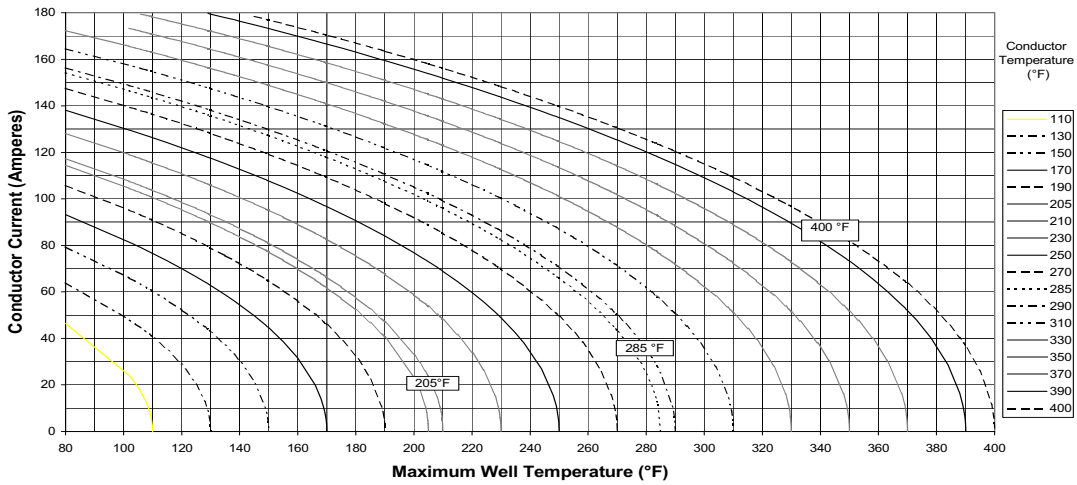


Figure 13—#1 Awg stranded round pump cable conductor temperature chart

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

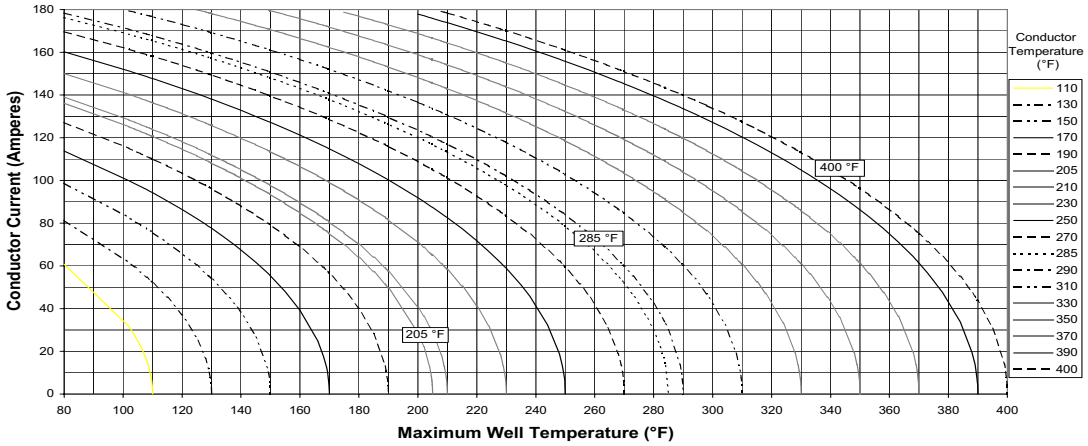


Figure 14—#1 Awg stranded flat pump cable conductor temperature chart

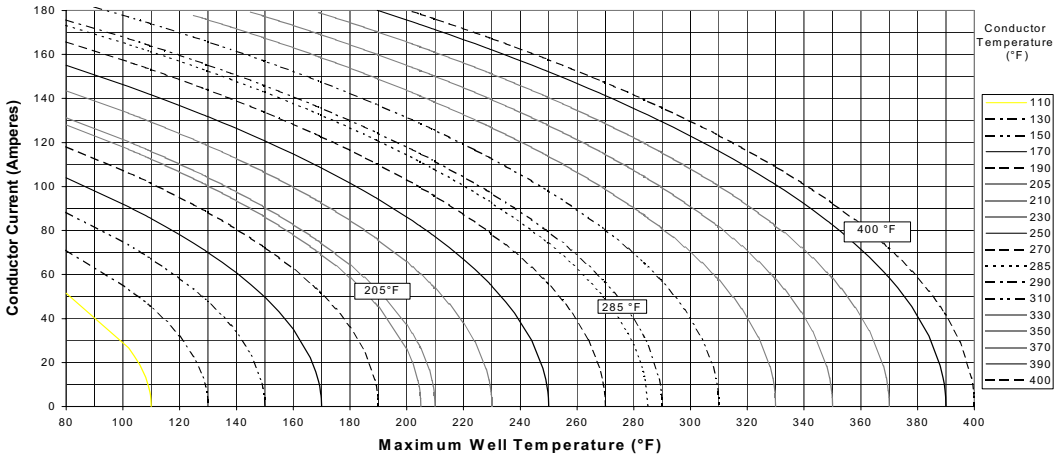


Figure 15—#1/0 Awg stranded round pump cable conductor temperature chart

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

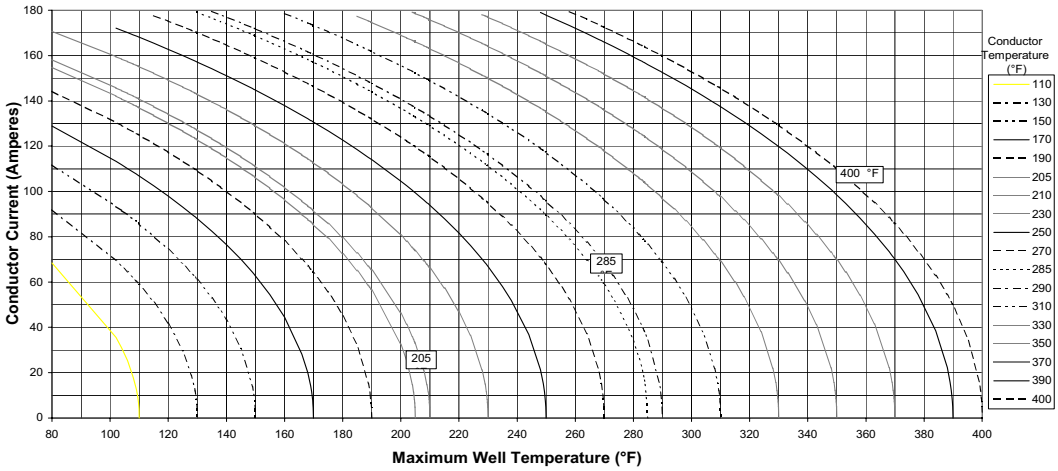


Figure 16—#1/0 Awg stranded flat pump cable conductor temperature chart

B.2 Polypropylene cables

Figure 17—Round cable normally used in wells where operating temperatures less than 80 ºC (176 ºF)

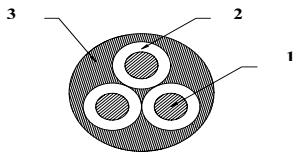
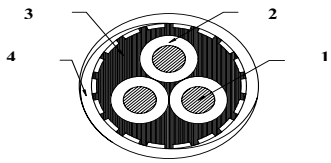


Figure 18—Round cable normally used in wells where operating temperatures less than 96 ºC (205 ºF)



Item	Description	Item	Description
1	Conductor, Copper	1	Conductor, Copper
2	Insulation, Polypropylene	2	Insulation, Polypropylene
3	Jacket, Polyethylene	3	Jacket, Nitrile
		4	Armor

All round cables have a physical filler to fill interstice.

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Figure 19—Flat cable normally used in wells where operating temperatures less than 96 ºC (205 ºF)

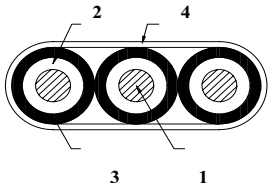
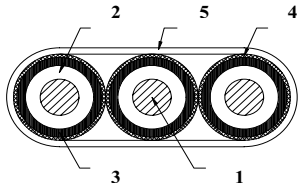


Figure 20—Flat cable normally used in wells where operating temperatures less than 96 ºC (205 ºF)



Item	Description	Item	Description
1	Conductor, Copper	1	Conductor, Copper
2	Insulation, Polypropylene	2	Insulation, Polypropylene
3	Jacket, Nitrile	3	Jacket, Nitrile
4	Armor	4	Barrier Layer
		5	Armor

B.3 EPDM cables

Figure 21—Round cable normally used in wells where operating temperatures less than 140 ºC (284 ºF)

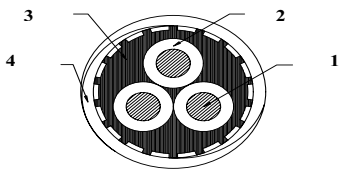
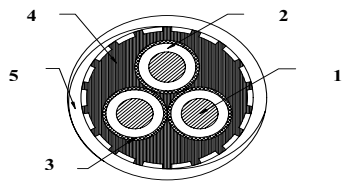


Figure 22—Round cable normally used in wells where operating temperatures less than 204ºC (400 ºF)



Item	Description	Item	Description
1	Conductor, Copper	1	Conductor, Copper
2	Insulation, EPDM	2	Insulation, EPDM
3	Jacket, Nitrile or EPDM	3	Barrier Layer
4	Armor	4	Jacket, Nitrile or EPDM
		5	Armor

All round cables have a physical filler to fill center interstice.

Copyright © 2005 IEEE. All rights reserved.

Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale

Figure 23—Flat cable normally used in wells where operating temperatures less than 140 ºC (284 ºF)

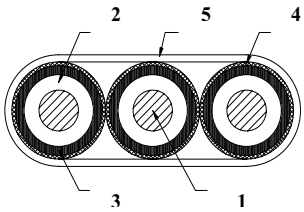
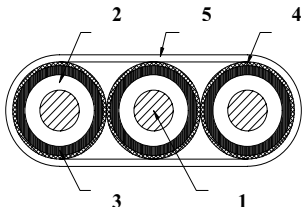


Figure 24—Flat cable lead sheath for harsh environments and temperatures less than 204 ºC (400 ºF)



Item	Description	Item	Description
1	Conductor, Copper	1	Conductor, Copper
2	Insulation, EPDM	2	Insulation, EPDM
3	Jacket, Nitrile or EPDM	3	Lead Sheath
4	Barrier Layer	4	Bedding Layer
5	Armor	5	Armor

Copyright © 2005 IEEE. All rights reserved.
Copyright The Institute of Electrical and Electronics Engineers, Inc.
Provided by IHS under license with IEEE
No reproduction or networking permitted without license from IHS
Not for Resale