Technical Report on Fire Resistance Improvements for API Flanges

API TECHNICAL REPORT 6F2
THIRD EDITION, APRIL 1999

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Upstream Segment

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Certain serious adverse health effects are associated with asbestos, among them the serious and often fatal diseases of lung cancer, asbestosis, and mesothelioma (a cancer of the chest and abdominal linings). The degree of exposure to asbestos varies with the product and the work practices involved.

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CONTENTS

Technical Report on Fire Resistance Improvements for API Flanges

1 Scope

This document establishes recommended methods for improving the performance of standard API flanges when subjected to the adverse effects of external high temperatures induced by exposure to fires. It does not cover fire prevention, suppression, or fire fighting practices.

Innumerable factors contribute to flange failures under fire conditions, so it is difficult to formulate hard and fast engineering rules which will ensure fire resistant behavior under all circumstances. It is possible to formulate a generalized methodology to examine enhancements which will increase the probability of survival of API flanges under fire conditions.

1.1 COMPARATIVE TESTING

To provide a basis for comparing protection methods it is necessary to provide consistent testing criteria. Although primarily used for valves, API RP 6F and API Spec 6FA, as well as other test procedures, listed in the following, have been used for testing connection and seal performances.

a. API RP 6F.
b. API Spec 6FA (supersedes API RP 6F).
c. User Modified API RP 6F, (Appendix A).
d. API Spec 6FB—Should be considered as the standard test method.

It is not intended that the order of listing indicates test severity.

2 References

1. API Spec 6AF
Specification for Fire Test for Valves, American Petroleum Institute, latest edition.

2. Weiner, Peter D.
Analysis of Flange and Clamp Joints Exposed to a Fire Environment, Mechanical Engineering Department, Texas A&M University, October 1979 (PRAC-79-21).

3. Fowler, Joe R.
Effects of Fire Environment on Pressure Capability of Standard API and ANSI Connections, prepared for the American Petroleum Institute, March 1981 (PRAC-80-33).

4. Fowler, Joe R.
Effects of Fire Environment on Pressure Capability of Standard API and ANSI Connections—Testing and Revised Analytical Procedure, prepared for the American Petroleum Institute, July 1982 (PRAC-81-33).

5. Fowler, Joe R. and Young, David S.
Prediction of Performance of 2"–6" ANSI Flanges and $2^{1}/_{16}$*"–*$7^{1}/_{16}$*" Clamps and Flanges in a Standard Fire Environment*, prepared for the American Petroleum Institute, July 1984 (PRAC-83-33).

6. API Spec 6A
Specification for Wellhead and Christmas Tree Equipment, American Petroleum Institute, latest edition.

7. API Spec 6D
Specification for Pipeline Valves (Gate, Ball, Plug and Check Valves), American Petroleum Institute, latest edition.

8. ANSI B16.5
Steel Pipe Flanges and Flanged Fittings, ASME.

9. *ASME Boiler and Pressure Vessel Code,*
Section VIII, Divisions 1 and 2.

10. Sweet, Harry J.
Prediction of Seating and Retaining Loads for API Type RX Pressure Energized Ring Joint Gaskets, prepared for the Association of Wellhead Equipment Manufacturers, April 1974.

11. Simmons, W. F., and H. C. Cross
Elevated Temperature Properties of Wrought Medium Carbon Alloy Steels, ASTM Special Technical Publication No. 199.

12. Miller, R. F., and J. J. Heger
Report on the Strength of Wrought Steels at Elevated Temperature, ASTM Special Technical Publication No. 100.

13. Smith, G. W.
Elevation of the Elevated Temperature Tensile and Creep Rupture Properties of 12 to 27% Chromium Steels, ASTM DS59.

14. Moon, D. P., R. C. Simon, and R. J. Favar
The Elevated Temperature Properties of Selected Superalloys, ASTM DS 7-S1.

15. Sweet, Harry J.
Summary of Design Equations for Clamp Type Connections prepared, for the Association of Wellhead Equipment Manufacturers.

16. Adamek, Frank, John J. Nutt, David S. Young
"Analysis of Bimetallic Clamp Type Connectors Subjected to Thermal Transients," prepared for the Fifth International Conference on Pressure Vessel Technology, September 9–14, 1984.

17. ASTM E-119
Standard Test Methods for Fire Test of Building Construction and Materials

18. ASTM E-84
Standard Test Method for Surface Burning Characteristics of Building Materials

3 Usage Considerations

3.1 DIVISIONS OF USE

It is important to recognize that API flanges utilized for conveying liquids as opposed to gases respond quite differently to fire environments. Rates of flow, as well as effluent composition, radically alter fire resistance.

Land wellheads and Christmas trees provide good heat sinks and consequently can be less vulnerable than flowlines.

Those multiple and adjacent wellheads, Christmas trees, and flowlines which are in confined or contained spaces, such as offshore platform installations, are an entirely different matter. Flame impingement from proximate wellheads may occur and convective cooling may be materially reduced. Drafting (convective air flow) may aid combustion with the realization of higher, more concentrated temperatures and total heat input. Conversely, under some fire conditions, this drafting effect can materially reduce ambient temperatures.

Other engineering problems must be addressed which do not come within the scope of this document, but should be considered when improving flange fire resistance. As an example, it does little good to protect the flanged connections of a short liquid flowline connecting two closed valves engulfed in a fire. Two events which may occur: (a) the overpressure induced by liquid expansion might cause flange separation, or (b) the flowline might catastrophically destruct resulting in damage greater than that experienced by a flange failure. The consequences of massive fire involvement are too numerous to discuss, but should be considered in designing for fire resistance of systems.

3.2 LIQUID AND GAS SERVICE

Installation and equipment considerations:

a. Onshore—Platform Offshore.
b. Flowing or Static—Effluent.
c. Wellhead—Size and Components.
d. Christmas Tree—Size and Components.
e. Flowline.

4 Testing

4.1 RELATIVE FIRE VULNERABILITY OF API FLANGES:

The performance of API and ANSI flanges in fire testing per API RP 6F and API Spec 6FA has been studied and is the subject of API Technical Report 6F1. Excerpts from that Technical Report are contained in Appendix B, and serve as a basic guideline to determine which flanges require protection.

4.2 MANUFACTURER'S TESTING:

At the present time, extensive testing has not been performed in accordance with API Spec 6FB. Various manufacturers have conducted tests in accordance with "user modified" API RP 6F, with a general concurrence that most or all API flanges will not survive without leakage or irreparable damage.

5 Improvements

5.1 METHODS OF IMPROVEMENT

5.1.1 Shielding

The most obvious protection is "shielding" or preventing the involvement of the flange with the fire environment. Metal shielding alone is not considered effective unless it is used with adequate insulation. Insulation inhibits heat transfer by radiation and convection. Used in conjunction, shielding and insulation can provide effective protection for flanges subjected to the testing outlined in API, Spec 6FA and API Spec 6FB. Shielding must be of sufficient thickness and made of an appropriate material to prevent "burn through" and to be self-supporting during a fire. Appendix C may be used to determine insulation requirement and provides information on some insulating materials. Many insulations are available; and information on physical properties can be obtained from the manufacturers.

Some important usage factors should be considered, including resistance to environmental deterioration; high insulating value; ease of installation; service life; and chemical interaction with flanges, studs, nuts, and shielding.

Shielding must cover the entire flanged connection and, in particular, studs and nuts.

5.1.2 Shielding Coatings

Coatings for fire protection have been widely used for construction members in refineries, and industrial and chemical plants. Many are used as external insulation for fired vessels. They are available in several forms: solid sheet materials; spray applied "gunite" or troweled types; batting (fiber); and wrapping-type materials. Most of these materials are rated in accordance with UL[1] and ASTM[2] specifications. ASTM-E 1119/ASTM-E 84 would be typical specifications. Numerous compositions are available, but generally fall into several categories: aluminum oxides blended with silica, or magnesium oxychlorides are typical. Trade compounds providing reactive bonding characteristics are added to make cementitious mixes for application. Common fiberglass and mineral woods are used. Consideration should be given to environmental considerations, water absorption, abrasion, impact resistance and compatibility with the materials being coated. To avoid covering studs and nuts, high temperature bolting materials may be used (see Appendix D).

[1]Underwriters Laboratories, 333 Pfingsten Road, Northbrook, Illinois 60062.
[2]American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959.

5.2 MATERIAL RECOMMENDATIONS

Most common materials used in API flange systems are carbon and low alloy steels which experience severe strength loss when exposed to high temperatures. Ferrous materials with significantly enhanced high temperature properties may be used to upgrade flange capabilities. Materials with exceedingly high capabilities are available but are expensive, limiting their usage to extremely critical applications. Some materials that should be considered are listed in Appendix D.

5.2.1 Geometric Changes

It is not contemplated that true geometric (dimensional) changes in API flanges will be considered. However, if an application (from a fire resistance standpoint) is marginal due to flange size or other factors, it might be possible to utilize a larger API flange that will meet the required criteria (see Appendix B).

5.2.2 Retrofit Possibilities—Materials

API flange joint failure (leakage) under fire conditions is directly related to significant degradation of physical properties, excessive or unequal expansion of components, distortion, etc. The single common result consequential to the failure is relaxation of the uniform loading (sealing) forces imposed on the seal elements: R, RX or BX rings. Some flanged connections, because of their size and/or service conditions, cannot be modified for fire resistance unless they are constructed of materials which will not exhibit detrimental physical changes under fire conditions. Others can be made fire resistant by changing only the studs and/or nuts to a suitable material.

There are three main mechanisms which may cause loss of sealing forces. First, the studs may yield due to loss of strength at elevated temperature. Second, the flange itself may yield under the nuts, causing the nuts to indent into the flange. Third, if the seal ring element is much stronger than the flange at elevated temperature, the sealing load may deform the flange. Differential thermal expansion is also a potential problem. If the studs expand more than the flanges, the sealing preload may be lost. If the flanges expand more than the studs, either the studs may yield or the nuts may indent into the flanges, causing leakage.

5.2.3 Retrofit Possibilities—Remachining

Possibilities exist that in the near future several field service agencies and manufacturers will obtain in situ remachining capabilities. The intent would be to provide flange seal modifications for use with proprietary sealing systems within the framework of standard API flange geometry. These services should be carefully examined and tested prior to inclusion into any piping system. Minimum requirements for use should be the methods and results of tests in accordance with API Spec 6FA and API Spec 6FB.

APPENDIX A—USER-MODIFIED API RP 6F

Flame temperature 1" from wall	2000°F (1100°C)
Stabilization temperature of internal seal surface	1200°F (650°C)
Total duration of heating	3 to $3^1/_2$ hours
Hold period at stabilization temperature	1 hour
Test pressure (High)	75% WP
[a]Test pressure (Low) gas service	500 psi
[a]Test pressure (Low) oil service	100 psi
Test media:	
During heat up and hold period	Water
During cool down	N_2
External leakage both during burn period and after cool down	0
External leakage after cool down at low pressure	0

[a]Qualification of 100 psi eliminates need for 500 psi test.

APPENDIX B—PERFORMANCE PREDICTIONS

B.1 Foreword

An analytical procedure to predict the performance of API Spec 6A and API Spec 6D standard end connections in the API Fire Test was developed in several research projects. In this Technical Report, these procedures are applied to API Spec 6A connections from $2^{1}/_{16}$ in. to $7^{1}/_{16}$ in., and API Spec 6D (ANSI) connections from 2 in. to 6 in.

The results show that the small, low pressure carbon steel joints are the most likely to leak. BX gaskets used in API joints are likely to unseat with 410 stainless bodies and A286 studs. API joints with 4130 bodies. B7 studs, and soft iron gaskets are relatively leak resistant. API 6B flanges and clamps with 410 stainless bodies and A286 studs are likely to leak.

Of the 170 connections studied, 87 are likely to leak; 29 are possible leakers; and 54 are not likely to leak.

B.2 Performance of API and ANSI End Connections in the Standard Fire Test of API Spec 6FA

B.2.1 INTRODUCTION

The prediction of whether or not a particular joint will fail in the fire test is based on three considerations.

a. Does the joint lose so much preload that it does not have enough left for the required seal retaining load?

b. Does the joint get so hot that the bolts or the connection yield?

c. Do the BX gaskets have enough elastic “spring-back” to keep from unseating?

Table B-2 shows the classification adopted in reporting possible leakage.

B.2.2 GENERAL

B.2.2.1 Actual required retaining loads to maintain a seal are not very well known. The *ASME Boiler and Pressure Vessel Code* requirements are guidelines, but they are likely conservative. Most joints that are classification B (50%–100% of required retaining load) probably won’t leak.

B.2.2.2 BX gaskets tend to unseat in small sizes with 410 stainless bodies and A286 studs (SA 453 Gr 660). There is no such tendency for 4130 bodies with B7 studs.

B.2.2.3 API 6B flanges and clamps with 410 stainless bodies and A286 studs are very poor in fire resistance. This is because of the greater thermal expansion with temperature of the bolts compared with the bodies.

B.2.2.4 The API flanges with 4130 material (60 ksi) and B7 studs, and soft iron RTJ gaskets are very fire resistant except for the smallest sizes and pressure range.

B.2.2.5 Although in many cases yielding of the flanges is predicted, this was usually ignored in the classification. This is because the calculation procedures for flange stresses are usually somewhat conservative, and because yielding at the surface of a flange or clamp does not result in significant permanent deformations until the yield is exceeded by a good margin.

Table B-1—Materials and Gaskets of Interest

Materials and Gaskets ANSI Flanges		
	Combinations	
	1	2
Flange Material	SA 105	316 SS
Bolt Material	SA 193 B7	SA 193 B8
Gasket Type	1. Spiral Wound 2. RTJ Type R	RTJ Type R
Gasket Material	1. Stainless 2. Soft Iron	Stainless
Materials and Gaskets API Flanges		
	Combinations	
	1	2
Flange Material	4130	410 SS
Bolt Material	SA 193 B7	SA 453 Gr 660
Gasket Type	RTJ	RTJ
Gasket Material	Carbon Steel	Stainless Steel

Table B-2—Classifications

A = When made up to normal specifications the joint has adequate retaining load and the BX gaskets will not unseat. No leakage is predicted.

B = When made up to normal specifications, the retaining load is between 50% and 100% of the code requirement. Leakage is possible.

C = Retaining load is less than 50% of the code requirement. Leakage is likely.

D = BX gaskets will unseat. Leakage is likely.

E = The yield strain of the bolt at temperature is between 75% and 100% of the makeup bolt strain. Therefore, leakage is likely.

F = The yield strain of the bolt at temperature is less than 75% of the makeup bolt strain. Leakage is almost certain.

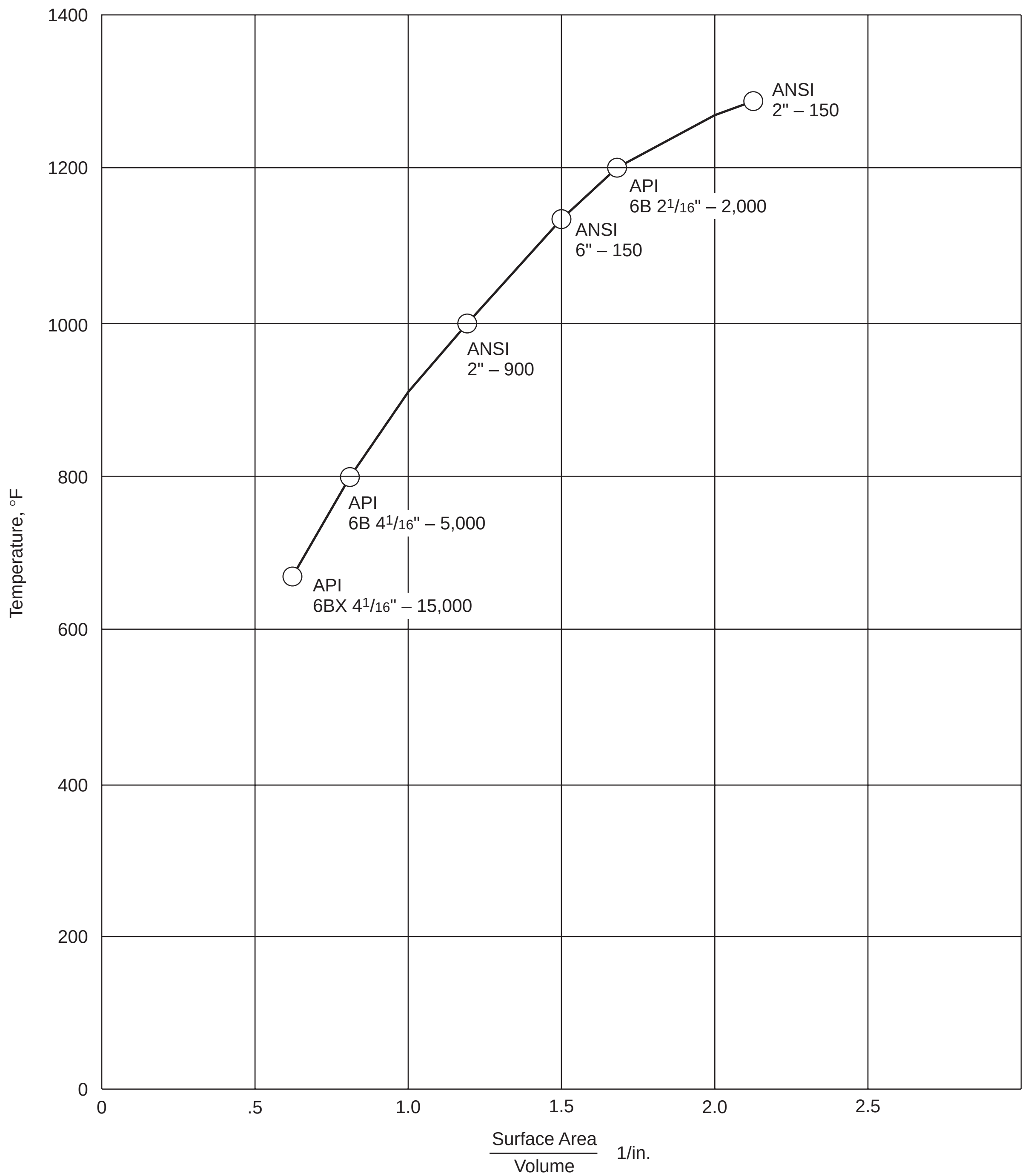


Figure B-1—Average Temperatures of Various Joints Carbon Steel at 30 Minutes

Table B-3—Classification Summary of ANSI Carbon Steel Flanges

Nominal Pipe Class Size in.	Class 150	300	400	600	900
2	F	F.B	—	E.C	A
$2^1/_2$	F	F	—	B	A
3	F	E.B	—	C	C
$3^1/_2$	F	E.B	—	C	—
4	E	B	B	C	B
5	F	B	B	C	B
6	F	B	B	C	B

Flat-Faced Spiral Wound Stainless Steel Gaskets

Nominal Pipe Class Size in.	Class 150	300	400	600	900
2	F	F	—	C,E	A
$2^1/_2$	E	E	—	B	A
3	E	A	—	C	C
$3^1/_2$	A	A	—	B	—
4	A	B	A	C	A
5	A	C	B	C	A
6	A	C	A	C	B

RTJ Soft Iron Gasket

Notes:
A = No leakage.
B = Retaining load 50% to 100% of required—leakage possible.
C = Retaining load less than 50% of required—leakage likely.
D = BX gasket unseats—leakage likely.
E = Bolts yield small amount—leakage possible.
F = Bolts yield large amount—leakage likely.

Table B-4—Classification Summary of 316 Stainless ANSI Flanges

Nominal Pipe Class Size in.	Class 150	300	400	600	900
2	A	A	—	B	A
$2^1/_2$	C	A	—	C	C
3	C	C	—	C	C
$3^1/_2$	C	C	—	C	—
4	C	C	C	C	C
5	C	C	C	C	C
6	C	C	C	C	C

Stainless RTJ Gasket

Notes:
A = No leakage.
B = Retaining load 50% to 100% of required—leakage possible.
C = Retaining load less than 50% of required—leakage likely.
D = BX gasket unseats—leakage likely.
E = Bolts yield small amount—leakage possible.
F = Bolts yield large amount—leakage likely.

Table B-5—Classification Summary of API Flanges and Clamps[a]

Size (Bore)	6B 2,000	6B 3,000	6B 5,000	6BX 10,000	6BX 15,000	Clamp[a] 5,000	Clamp[a] 10,000
$2^1/_{16}$	F	E	A	E	A	E	F
$2^9/_{16}$	F	A	A	A	A	E	F
$3^1/_{16}$	A	A	A				
$3^1/_8$	F	A	A	A			
$4^1/_{16}$	A	A	A	A	A	A	A
$5^1/_8$	A	A	A	A	A		
$7^1/_{16}$	A	A	A	A	A	E	A

4130 Material—B7 Studs

Size (Bore)	6B 2,000	6B 3,000	6B 5,000	6BX 10,000	6BX 15,000	Clamp[a] 5,000	Clamp[a] 10,000
$2^1/_{16}$	C	C	C	D	D	C	C
$2^9/_{16}$	C	C	C	D	D	C	C
$3^1/_{16}$	A	D	C				
$3^1/_8$	C	C	C	C			
$4^1/_{16}$	C	C	C	A	A	C	C
$5^1/_8$	C	C	C	A	C		
$7^1/_{16}$	C	C	C	A	A	C	C

410 SS Material—A286 Studs

Notes:
A = No leakage.
B = Retaining load 50% to 100% of required—leakage possible.
C = Retaining load less than 50% of required—leakage likely.
D = BX gasket unseats—leakage likely.
E = Bolts yield small amount—leakage possible.
F = Bolts yield large amount—leakage likely.

[a]Clamp-type connections are covered in API Specification 16A, *Specification for Drill Through Equipment*.

B.3 Conclusions and Guidelines

B.3.1 Small diameter, low pressure connections in carbon steel are very likely to leak. This is because they get too hot, and yielding of the B7 bolts occurs.

B.3.2 A user could provide protection against leakage of these joints in a fire by insulating the joints or by using a joint that is one or two pressure classes higher than what is required for pressure alone.

B.3.3 Bodies of 410 stainless with A286 studs are BX gaskets should not be used in sizes smaller than $4^1/_{16}$" for fire service. These gaskets are likely to unseat.

B.3.4 API 6B flanges and clamps with 410 stainless bodies and A286 (SA 453 660) bolts are very likely to leak in a fire test because the bolts expand so much more than the bodies. As a general rule, it is good practice to match the expansion coefficients of the bolts and bodies.

B.3.5 The actual seal retaining loads required to prevent leakage are not well known. The retaining loads required by the *ASME Boiler and Pressure Vessel Code* are probably very conservative.

B.3.6 There is possibly a wide variation in results from those predicted here because of the variability of test facilities, uncertainties of makeup, variations in actual material strengths, and variations in gaskets. However, those results should be indicative of comparative strengths.

B.3.7 Users can improve the performance of some joints by making them up as tight as possible while avoiding overstressing them. This may require the use of torque wrenches or stud tensioners in the field.

B.3.8 API flanges with 4130 bodies and carbon steel RTJ gaskets are relatively good in the fire test (except for the small, low pressure sizes). This is because the predicted retaining loads of these gaskets are small, and because the makeup bolt loads are much higher than the equivalent ANSI flanges.

B.3.9 Of the 172 connections studied, the breakdown is as follows:

Category	Number	Percent
A = No leakage	54	32
B = Low retaining load, leakage possible	16	9
C = Very low retaining load, leakage likely	67	39
D = BX Gasket unseated, leakage likely	5	3
	(5 of 22, or 23% of BX joints)	
E = Bolts yield some, leakage possible	13	8
F = Bolts yield a lot, leakage likely	15	9

APPENDIX C—DETERMINATION OF INSULATION REQUIREMENTS TO PROTECT FLANGE

The basic methodology used in this Appendix is explained in References 3, 4, and 5 of section 2, References.

The following equation, which is based on the assumption of negligible internal thermal resistance of a flanged connection, predicted the average connection temperature of an uninsulated connection fairly accurately comparing with both test data and finite element methods.

$$\frac{T_\infty - T}{T_\infty - T_o} = e^{-(hA/\rho CV)\theta}$$

where

T_a = Flame temperature (1500°F for API Spec 6FA),

T = Average temperature of joint, °F,

T_o = Starting temperature (70°F),

h = External convection coefficient,

$$10\frac{Btu}{\text{hr} - \text{ft}^2 - {}^\circ\text{F}}.$$

for the facilities where testing was done. It can be different at different facilities.

A = All joint surface areas exposed to flame, ft^2,

ρ = Density, lbm/ft^3,

C = Specific heat Btu/lbm °F,

V = Joint metal volume, tapered hub plus flanges, ft^3,

θ = Time, hours.

This equation can also be used, as a first approximation, to determine the equivalent external convection coefficient from insulation which is required to keep the flange below a given temperature in the test.

If we assume, for example, that the flange will be protected if it does not exceed 800ºF, then the required external convection coefficient needed to achieve that can be found.

$$\frac{T_\infty - T}{T_\infty - T_o} = \frac{1500 - 800}{1500 - 70} = 0.4895$$

$$e\left(\frac{hA}{\rho CV}\theta\right) = \frac{1}{0.4895} = 2.0429$$

$$\left(\frac{hA}{\rho CV}\theta\right) = ln(2.0429) = 0.7143$$

For carbon steel,

$$\theta = \frac{1}{2}\text{ hour } \rho = 490\text{ lb/ft}^3$$

$$C = 0.11\frac{Btu}{\text{lb}_m{}^\circ\text{F}}$$

$$\frac{hA}{V} = 0.7143\ (490\ \text{lb/ft}^3).11\frac{Btu}{\text{lb}_m{}^\circ\text{F}}\ \frac{1}{{}^1/_2\text{ Hour}}$$

$$\frac{hA}{V} = 77\frac{Btu}{\text{hr/ft}^3 - {}^\circ\text{F}}$$

As an example, take an ANSI 2"–150 lb flange

$$\frac{A}{V} = 2.11/\text{in.} = 25.4/\text{ft}$$

$$h\text{ required} = \frac{77}{25.4} = 3.04\ \frac{Btu}{\text{hr} - \text{ft}^2 - {}^\circ\text{F}}$$

This is the equivalent external convection coefficient which the insulation must simulate to keep the connection at 800ºF.

The insulation thickness required can be calculated based on the thermal conductivity of the insulation.

For two-dimensional planer insulation, the relationship between equivalent convection coefficient and insulation properties, assuming the outside of the insulation is at the flame temperature, is

$$h = \frac{K}{t},$$

K = thermal conductivity $\frac{Btu}{\text{hr} - \text{ft}^2 - {}^\circ\text{F}}$,

t = thickness.

To consider a curved surface (as in a flange outside diameter) the equation is

$$h = \frac{K}{r_f\, ln\left(\frac{r_o}{r_f}\right)}$$

where

r_f = outside radius of the flange,

r_o = outside radius of the insulation.

Using the two above equations, the relationship between insulation thickness and required thermal conductivity is

	K required $\frac{Btu}{\mathrm{hr} - \mathrm{ft} - {}^{\circ}\mathrm{F}}$	
t Insulation Thickness, in.	Flat Section	Curved Section $r_f = 3"$
		(2"–150 lb flange)
0.25	0.063	0.061
0.50	0.127	0.117
1.00	0.249	0.219

These thermal conductivities are readily available.

The conclusion is that relatively thin insulation will provide adequate protection to even the smallest flanges.

APPENDIX D—FLANGE, SEAL, AND BOLT MATERIALS

D.1 The following material properties are important when evaluating materials for fire resistant flanges.

a. Yield strength.
b. Rupture strength.
c. Coefficient of thermal expansion.
d. Thermal conductivity.
e. Elastic modulus.
f. Poisson’s Ratio.

D.2 Table D-1 contains these properties at ambient and elevated temperature. The following criteria should be considered when selecting materials for use in fire resistant flanges:

a. Reduction in initial tightening force in bolts due to increased bolt expansion relative to flange.
b. Preload loss due to flange rotation because of thermal gradient distribution across flange cross-section.
c. Material properties related to stiffness (Young’s Modulus and Poisson’s Ratio) change with temperature.
d. High reduction in yield strength at elevated temperatures.
e. Differential thermal expansion coefficients and thermal conductivities may affect sealing, bolting, etc.

Table D-1—High Temperature Material Properties

	70°F			1200°F						
	Heat Treat	Yield (KSI)	Tensile (KSI)	E 10E6 PSI	Yield (KSI)	Tensile (KSI)	E 10E6 PSI	SR-10 (KSI)	Alpha 10E-6/F	K
Carbon Steels										
1020[c]	H.R.	38.0	63.0	27.9	11.0	22.0	—	>14.0[a]	8.0	19.5
Low Alloy Steels										
4130	Q&T	60.0	90.0	29.9	—	—	11.2	—	8.5	—
4140	Q&T	60.0	90.0	29.9	—	—	—	—	—	—
A 193 B7	Q&T	105.0	29.9	15.8	—	—	11.2	—	8.5	—
1 1/4% Cr, 1/2% Mo[d]	Ann.	36.0	—	27.9	10.0	—	10.6[b]	—	8.4	—
Cr-Mo-V	N, Q&T	88.5	106.0	29.9	41.5	47.4	—	16–35	—	—
2 1/4% Cr, 1% Mo[d]	Ann.	37.1	73.1	30.2	23.2	26.0	16.2	20.0	7.9	19.5
Stainless Steels										
316[c]	Ann.	30.0	74.9	28.0	16.1	46.6	20.9	>21.0	10.4	10.5
410	Q&T	60.0	90.0	29.2	18.9	—	12.2	—	6.6	15.3
A286 Grade 660	S.T./Age	94.4	161.2	29.2	82.3	126.0	22.2	68.4	9.5	10.2
High Temp Alloys										
625	Ann.	77.5	135.0	30.1	62.0	120.0	24.7	90.0	8.2	8.3
X750	P.T.	118.5	174.0	31.0	103.0	136.5	23.0	100.0[b]	8.4	9.4
718	Ann./Age	150.0	180.0	29.0	115.0	140.0	23.7	>100.0	88.6	9.5
718 (NACE)	Ann./Age	115.0	130.0	29.0	—	—	23.7	—	8.6	9.5

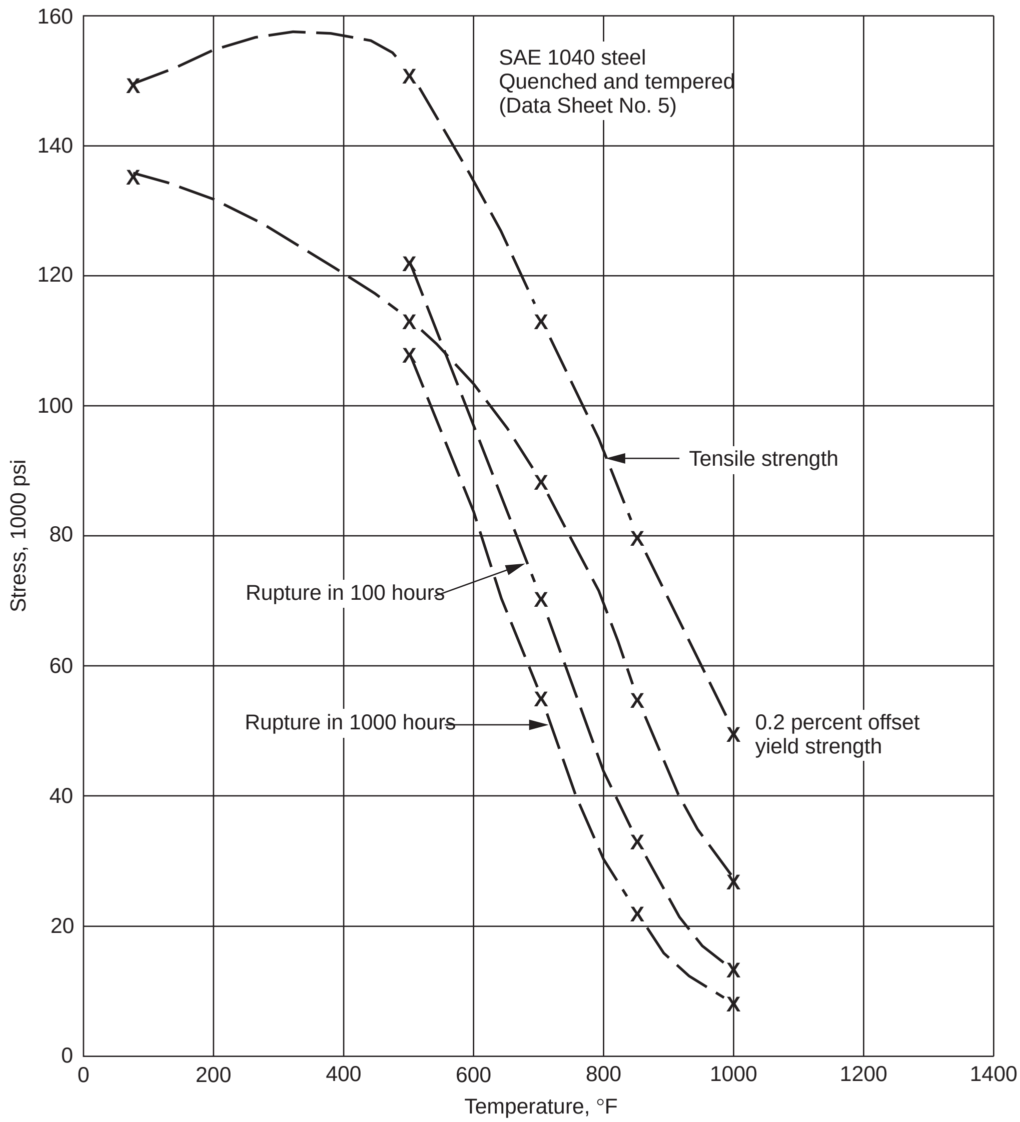
Property Definition

Yield	0.2% Offset Yield Stress
Tensile	Tensile Stress
E	Young’s Modulus
SR-10	10 hour rupture stress
Alpha	Mean Thermal Expansion Rate: 70°F –1200ºF
K	Mean Thermal Conductivity: (Btu/hr-ft. º F)

Heat Treat Key

H.R.	Hot Rolled
Q	Quenched
Amn.	Annealed
N	Normalized
T	Tempered
S.T.	Solution Treated
Age	Age Hardened
P.T.	Precipitation Hardened

[a]Property at 1,000°F.
[b]Extrapolated.
[c]Cannot be heat treated to obtain AP Type II or III properties.
[d]Can be heat treated to obtain API properties; however, high temperature material properties in this condition are not available.



Source: Elevated Temperature Properties of Carbon Steels
ASTM Special Technical Publication #180
University of Houston Library TX 47255

Key
1 = Material Table D-3 with $^1/_2$ inch insulation
2 = Material Table D-3 with 1 inch insulation
3 = Material Table D-3 with $1^1/_2$ inch insulation
4 = Material Table D-3 with 2 inch insulation
5 = Material Table D-4 with $^1/_2$ inch insulation
6 = Material Table D-4 with 1 inch insulation
7 = Material Table D-4 with $1^1/_2$ inch insulation
8 = Material Table D-4 with 2 inch insulation
9 = Material Table D-3; no insulation required
10 = Material Table D-4; no insulation required
N.R. = Not recommended

A thermal conductivity (K) of 0.20 Btu/hr-ft°F was used to determine the required insulation thicknesses. If an insulation of a higher thermal conductivity is substituted, the equivalent insulation thickness can be determined using the following method:

$$t_2 = \frac{Kt_1}{0.20}$$

t_2 = required insulation thickness of new insulating material (in.),

K = thermal conductivity of new insulating material. (Btu/hr-ft–°F),

t_1 = insulation thickness recommended in chart (in.).

High Temperature Strengths From Data Sheet No. 5 Killed Carbon Steel (0.27–0.58°C)

Table D-2—Suggested Fire Protection of Flanges

				API Pressure Rating			
Size (in.)	2000 psi	3000 psi	5000 psi	10,000 psi	15,000 psi	20,000 psi	FPC
				1	9	9	A
$1\frac{13}{16}$				2 or 5	2 or 5	2 or 5	B
				N.R.	8	7	C
	1 or 2	1	9	1	9	9	A
$2\frac{1}{16}$	6	2 or 5	2 or 5	2 or 5	2 or 5	1	B
	N.R.	8	8	N.R.	8	7	C
	2 or 5	9	9	9	9	9	A
$2\frac{9}{16}$	2 or 5	2 or 5	2 or 5	2 or 5	2 or 5	1	B
	N.R.	8	8	8	8	7	C
	2 or 5	9		9	9		A
$3\frac{1}{16}$	2 or 5	2 or 5		2 or 5	2 or 5		B
N.R.	8			8	7		C
			9				A
$3\frac{1}{8}$			2 or 5				B
			8				C
	9	9	9	9	9	9	A
$4\frac{1}{16}$	2 or 5	2 or 5	2 or 5	1	1	1	B
	8	8	7	7	7	4 or 6	C
$5\frac{1}{8}$				9			A
				1			B
				7			C
	9	9	9	9	9	9	A
$7\frac{1}{16}$	2 or 5	2 or 5	1	1	1	1	B
	8	7	7	4 or 6	4 or 6	3 or 6	C
	9	9	9	9	9	9	A
9	2 or 5	1	1	1	1	1	B
	7	7	4 or 6	3 or 6	3 or 6	2 or 5	C
	9	9	9	9			A
11	1	1	1	1			B
	7	4 or 7	3 or 6	3 or 6			C
	9	9	9	9	9		A
$13\frac{5}{8}$	1	1	1	1	1		B
	7	4 or 6	3 or 6	3 or 6	7		C
	9	9	9	9			A
$16\frac{3}{4}$	1	1	1	1			B
	4 or 6	4 or 6	3 or 6	3 or 6			C
	9	9					A
$17\frac{3}{4}$	1	1					B
	4 or 6	3 or 6					C
			9	9			A
$18\frac{3}{4}$			1	1 or 10			B
			3 or 6	2 or 5			C
		9					A
$20\frac{3}{4}$		1					B
		3 or 6					C
	9		9	9			A
$21\frac{1}{4}$	1		1	1 or 10			B
	4 or 6		2	2 or 5			C

D.3 Fire Protection of Flanges

D.3.1 This section contains guidelines for the fire protection of 6A flanges. The method contained in Appendix C of this bulletin has been used to determine these guidelines. The following assumptions were also made:

D.3.1.1 Flanges made of low alloy steels (Table D-3 Materials) will withstand average flange temperature of up to 800°F. This is based on the fact that the mechanical properties of these materials degrade significantly above this temperature.

D.3.1.2 Flanges made of intermediate alloy materials (Table D-4 Materials) will withstand average flange temperatures of up to 1200°F. The mechanical properties of these materials begin to degrade significantly above this temperature.

Stress levels present in individual flanges have not been considered. This simplification is valid if one considers the significant reduction in material properties which takes place after the allowable temperatures.

D.4 Since no two applications are identical, flange protection has been subdivided into three classes: A, B, and C. Class A offers the lowest amount of fire resistance, while class C offers a greater degree of fire resistance. No flange, however, can be made "fireproof." A fire of sufficient magnitude will cause flanges protected by all of these categories to fail. These recommendations are therefore offered only as guidelines.

D.4.1 CLASS A

This class is intended to protect flanges from fires of moderate severity and short duration. A 1600°F fire for a period of 30 minutes was used for analysis purposes in establishing this class. Many of the intermediate and larger size flanges possess this degree of fire resistance without any modifications provided they are manufactured from the proper materials. This has been verified by testing and more in-depth analysis, which is documented in Appendix B. In all cases, the results using the analysis from Appendix C are conservative in comparison to the analysis and test results of Appendix B. Where testing and more in-depth analysis have been performed, these results have been substituted.

Table D-3—Commonly Used Materials
Low Alloy Steels

Flange and Seal Material	Bolting Material
AISI 1040	ASTM A193 Grade B7 studs
AISI 4130	with A194 Grade 2H nuts.
AISI 4140	or
$1^1/_4$ Cr –1 Mo	ASTM A193 Grade B7M studs
ASTM 487 Grade 4Q–9Q	ASTM A194 Grade 2M nuts.

Table D-4—Intermediate Steels/High Alloy Bolting

Flange and Seal Material	Bolting Material
Cr–Mo V	AISI 718
$2^1/_4$ Cr–1 Mo	AISI X750
Nitronic 50	ASTM A283 Grade 660
	ASTM A453 Grade 660
	ASTM A638 Grade 660

Notes:
1. Young's Modulus and/or the coefficient of thermal expansion of the flange, seal, and bolting materials in Table D-4 have been matched between the dotted lines. Flange and seal materials should not be exchanged with bolting materials above or below the dotted line.
2. Flange bolting should be prestressed to 75% of yield strength at ambient temperature.
3. These material tables are to be used as a guide for selecting appropriate flange and bolting combination to suit a particular high temperature application. These tables in no way attempt to limit or restrict the usage of materials not listed. In selecting materials not included in this list, care should be taken to assure material strength and thermal expansion coefficients are compatible and will withstand the anticipated fire temperatures.

Example Problem:

A $7^1/_{16}$ in. API 10,000 psi gate valve is to be used as the lower master valve on an offshore wellhead assembly. Devise a suitable means of fire protection for the flanges of this valve, and the wellhead flanges to which the valve will be connected.

Considering the offshore location, Fire Performance Class C is selected. Consulting Table D-2 in this Appendix for Fire Performance Class C, Material Table D-3 with 2 in. of insulation (K = 0.20 Btu/hr-ft.°F) is recommended).

The valve manufacturer is consulted and it is determined that the valve body and flanges are to be 4140 material. 4140 material is chosen for the mating flange and gasket also since they identically match the thermal expansion rate of the valve's flange.

ASTM A193 Grade B7M studs and A194.2M nuts are selected because the flange will be covered with a shroud and hydrogen sulfide potentially retained in contact with the bolting.

An insulating material with a K value of 0.12 Btu/hr.-ft-°F is to be used. The alternate insulation thickness is determined as shown below:

$$t_o = \frac{Kt_1}{0.20} = \frac{(0.12)(2.0)}{0.20} = 1.20 \text{ inch}$$

round up to 1.25 inch

A sketch of the shrouded flange assembly is shown in Figure D-1.

D.4.2 CLASS B

This class is intended to protect flanges from more severe fires, and fires of short duration. A 2300°F fire for a period of 30 minutes was used for analysis purposes in establishing this class. The recommendations of this fire performance class have been subject to only very limited testing at this time.

D.4.3 CLASS C

This class is intended to protect flanges from severe fires of longer duration. A 2000°F fire for a period of three hours was used for analysis in establishing the recommendations of this class. Presently no testing has been performed under these fire conditions.

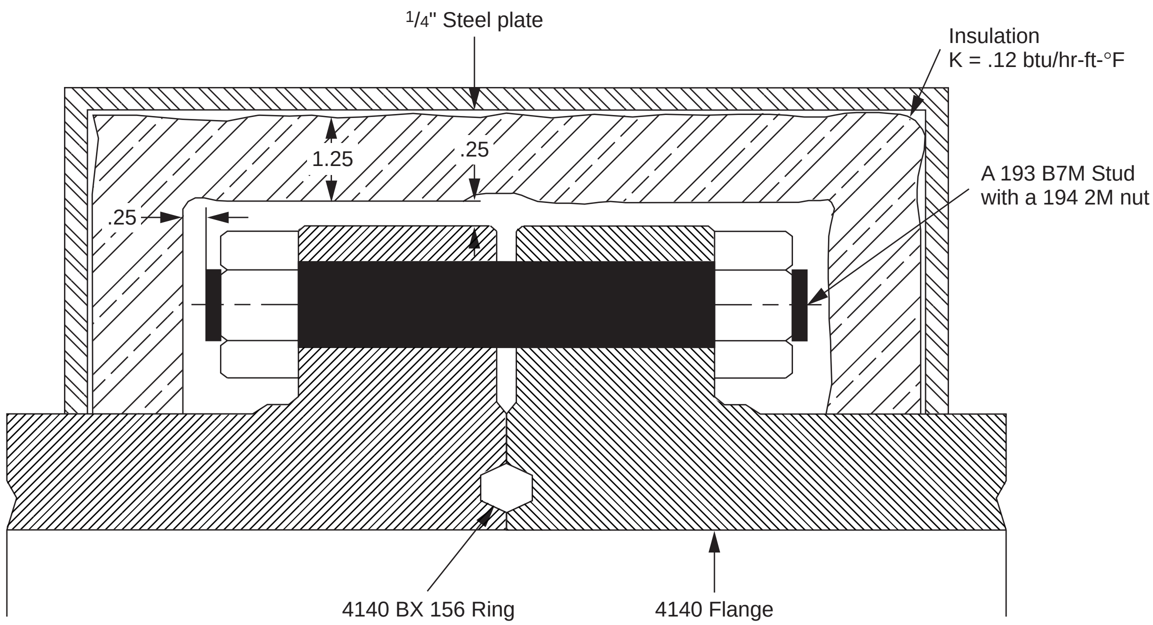


Figure D-1—7 $^{1}/_{16}$ in. API 10,000 psi Flange Protector in Accordance with Fire Protection Class C

APPENDIX E—METRIC CONVERSIONS

E.1 English units are preferred in all cases and shall be standard in this specification. The following factors are from API Std 2564:

Length:	1 inch (in.)	=	25.4 millimeters (mm)
Pressure:	1 pound per square inch (psi)	=	0.06894757 bar
Stress:	1 pound per square inch (psi)	=	0.0006894757 megapascals (MPa)
Energy:	1 foot-pound (ft-lb)	=	1.355818 Joule (J)
Torque:	1 foot-pound (ft-lb)	=	1.355818 Newton-meter (N-m)
Mass:	1 pound mass	=	0.453524 kilogram (kg)

Temperature Conversion: The following formula may be used to convert degrees Fahrenheit (°F) to degrees Celsius (°C):
°C = (5/9) (°F–32)

E.2 In addition to the above conversions, the designations PN for nominal pressure and DN for nominal diameter are sometimes used in the designation of valves. For the purposes of this specification, the PN designations relate to the pressure classes, and the DN designations relate to NPS, or nominal pipe sizes, as follows:

Class 150	=	PN 20	Class 300	=	PN 50
Class 400	=	PN 64	Class 600	=	PN 110
Class 900	=	PN 150	Class 1500	=	PN 260
Class 2500	=	PN 420			

NPS 2	=	DN 50	NPS 2 $^1/_2$	=	DN 65
NPS 3	=	DN 80	NPS 4	=	DN 100

For NPS 4 and greater listed sizes, multiply the NPS by 25 to obtain the DN, except that there is no equivalent for NPS 36.

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