WSRC-MS-95-0157
CONF-951135--22

Temperature Impacts on the Set Pressure of Soft Seated Pressure Relief Valves

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A document prepared for INTERNATIONAL MECHANICAL ENGINEERING CONGRESS AND EXPOSITION at San Francisco from 11/12/95 - 11/17/95.

DOE Contract No. DE-AC09-89SR18035

DISCLAIMER

TEMPERATURE IMPACTS ON THE SET PRESSURES OF SOFT-SEATED PRESSURE RELIEF VALVES

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ABSTRACT

From a safety standpoint, regardless of plant or facility type, the most important pieces of equipment are the pressure relief devices. The most critical characteristics of a pressure relief device are its set pressure and the related relieving capacity.

The **Set Pressure** of a pressure relief device is defined as that value of increasing inlet static pressure at which the discharge becomes continuous (ASME PTC 25-1994, Performance Test Codes)[1]. To preclude an unsafe overpressure situation, the set pressure of the pressure relief device must not exceed the maximum allowable working pressure of the equipment or system being protected.

Because of testing facility limitations, size or pressure, pressure relief valves intended for elevated temperature service are often set using ambient temperature air. Adjustments are made to the ambient valve opening pressures to compensate for the temperature differences.

The extent of the adjustments to the pressure relief valve set pressure is important to ensure the valve will provide the required overpressure protection at the elevated in-service temperature.

COMMON EXPECTATIONS FOR SETTING OF SOFT-SEATED VALVES UNSAFE

Typically, an **increase** of temperature will result in a **decrease** of the pressure relief valve opening pressure, established at ambient temperature, because of the reduction of the forces keeping the valve closed.

Figure 1 shows a typical set pressure reduction of a metal-to-metal seated pressure relief valve set at 150 PSIG, ambient temperature, when heated to service conditions of approximately 360 degrees F. The opening pressure of the valve was reduced from 150 PSIG ambient to 146 PSIG at service temperature -- or approximately 3 percent reduction.

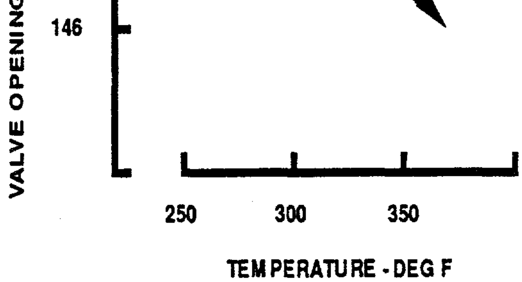

FIGURE 1

TYPICAL REDUCTION OF SET PRESSURE AT ELEVATED TEMPERATURES

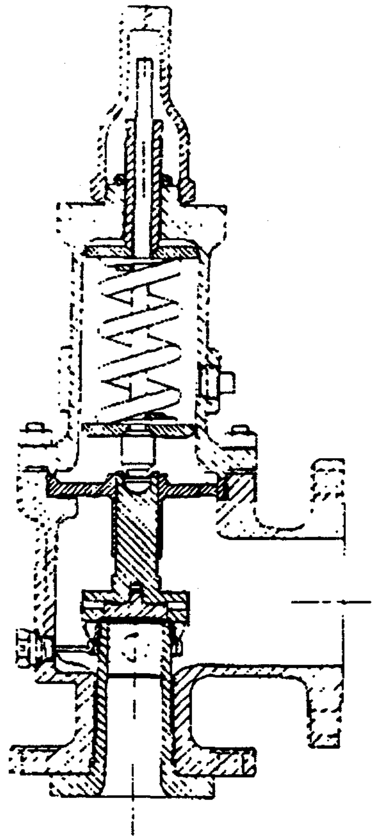

FIGURE 2

TYPICAL METAL-TO-METAL SEAT RELIEF VALVE

Figure 2 shows a typical high temperature, metal-to-metal seated pressure relief valve. The forces generated by the compressed spring keep the valve closed until the inlet pressure multiplied by the seat area produces sufficient opening forces.

As the temperature increases, the pressure relief valve spring rate, pounds per inch of compression, is reduced. Thermal expansion of the valve parts associated with the spring compression also reduces the spring forces. In some cases, the seat diameter expands increasing the opening forces at the same inlet pressure. The impact of the elevated temperature on the metal-to-metal seated valve is typically a reduced opening pressure.

Pressure relief valves opening at below set pressure tolerances could cause dangerous operating conditions, degrade the environment, damage equipment, reduce productivity, etc..

To compensate for the temperature impacts on the set pressure of this pressure relief valve, the valve is set at approximately 154 PSIG -- or 103% of set pressure -- at ambient temperatures.

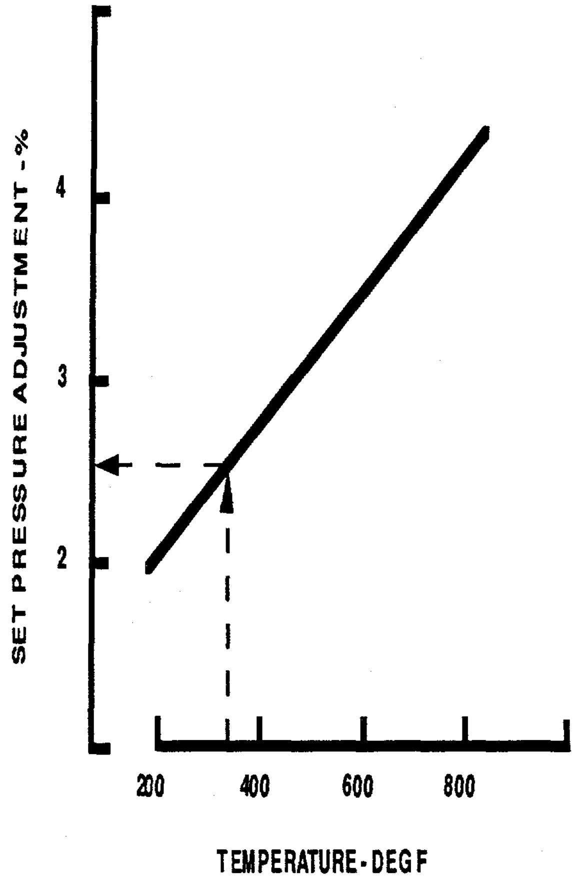

FIGURE 3

TYPICAL PERCENTAGE OF SET PRESSURE ADJUSTMENT TO COMPENSATE FOR TEMPERATURE

This adjustment is named **Cold Differential Test Pressure**, which is defined as the inlet pressure the pressure relief valve is adjusted to open on the test stand [1]. "Test Pressure" is used because the actual set pressure of the valve is at the in-service operating conditions.

Because of operational and structural reasons, the pressure relief valve spring is normally selected to satisfy set pressure requirements at the elevated temperature conditions. A higher rated spring is not used to adjust for the cold differential test pressure as the higher rated spring might provide excessive forces at the in-service conditions.

The cold differential test pressure also includes any compensation for superimposed back pressure and/or temperature. This Technical Paper deals only with temperature impacts on pressure relief valve set pressures.

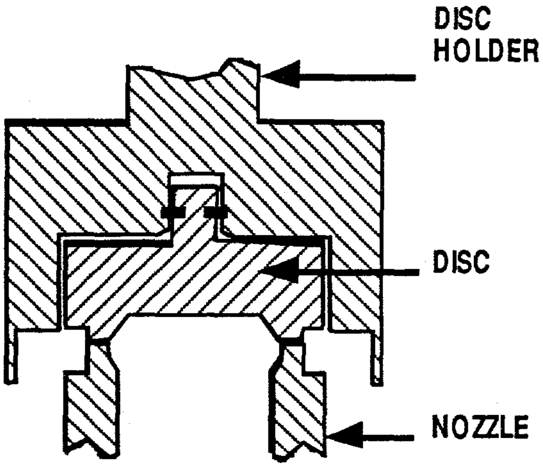

FIGURE 4

METAL-TO-METAL SEAT CONFIGURATION

Figure 4 shows a typical metal-to-metal pressure relief valve configuration. The components shown are capable of withstanding very high temperatures.

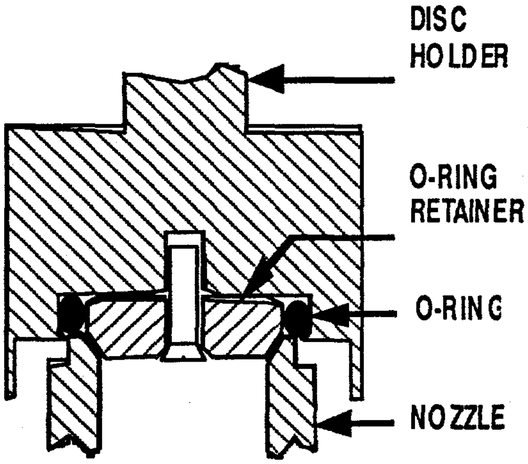

FIGURE 5

RESTRAINED O-RING, SOFT SEAT CONFIGURATION

Figure 5 shows a typical soft seat configuration. The pressure relief valves using this configuration are usually limited to temperatures of up to 500 degrees F.

Soft-seated pressure relief valves are selected for many reasons including better seat tightness closer to the set pressures, inherent compensation for minor misalignments of the seating parts, improved ability to withstand vibration and corrosive services, better survivability from discharge erosion and materials impacts, etc., than metal-to-metal seated valves.

In the Figure 5 configuration, the O-Ring is restrained on three sides permitting thermal expansion only towards the pressure relief valve nozzle. The O-Ring materials for steam service valves include Teflon and ethylene-propylene. The thermal expansion rate of the typical O-Ring material is approximately 30 * 10^-6 inches per inch per degree F versus approximately 10 * 10^-6 inches per inch per degree F for the associated metal parts.

Furthermore, examination of the soft seat materials after exposure to elevated temperatures, even for short durations, disclosed the materials had hardened -- increased durometer values.

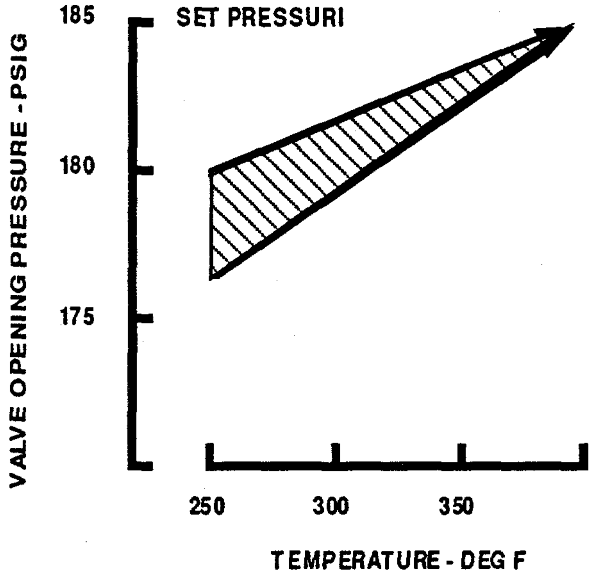

FIGURE 6

RESTRAINED O-RING SEAT -- TYPICAL INCREASE IN OPENING PRESSURE AT ELEVATED TEMPERATURES

Testing of restrained O-Ring, soft-seated pressure relief valves at ambient and elevated temperature conditions disclosed the opening pressures **increased** as the temperatures **increased.**

The combination of the dimensional and hardness changes to the restrained O-Ring seats increased the forces required to open the pressure relief valves. The increases in the forces exceeded the actions related to the decreasing opening forces in metal-to-metal seated valves. Therefore, the soft- seated valve opening pressures increased with increases in temperature.

Various pressure relief valves, set to open at 185 PSIG in steam service, displayed this reduced opening pressures at ambient characteristic. The opening pressures for the restrained O-Ring soft-seated valves increased approximately three to four percent from the ambient to service temperature, as shown in Figure 6.

This soft-seated pressure relief valve opening pressure **increase** with increasing temperature is contrary to the **decrease** of opening pressures of metal-to-metal seated valves.

The ASME Boiler & Pressure Vessel Code (ASME Code)[2] Section VIII does not require the manufacturers of the pressure relief valves to identify the cold differential test pressures for their valves in their publications, such as catalogs, etc., available to the users and valve testing facilities personnel.

Where cold differential test pressure is provided in the catalogs, the data usually indicate an opening pressure decrease with increased temperatures. Furthermore, the data are usually not identified to any seat type. Pressure relief valve users and testing personnel are led to conclude that, for all valves, the opening pressure at ambient conditions should be increased, as shown in Figure 3.

Discussions have shown that even some pressure relief valve manufacturers and assemblers were not aware that the opening pressure of soft-seated valves increased with increased temperatures. In their defense, manufacturers and assemblers normally test and set their valves at the elevated temperature conditions.

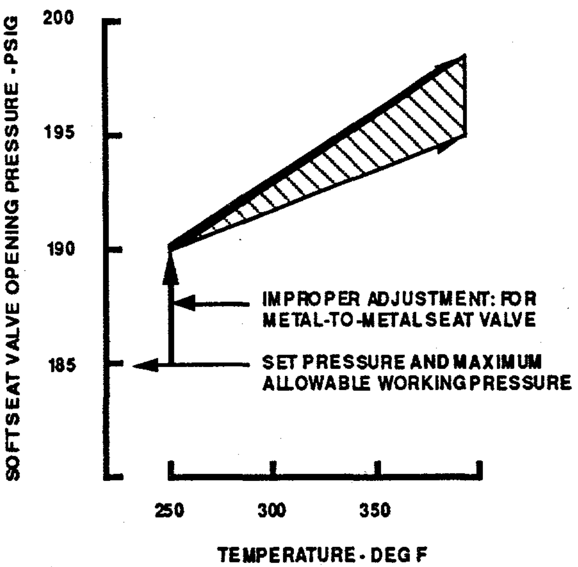

FIGURE 7

UNSAFE CONDITION CAUSED BY ADDING METAL-TO-METAL SEAT TEMPERATURE ADJUSTMENT TO SOFT SEAT VALVES

Figure 7 shows the dangerous consequences of not being aware that the opening pressure of a soft-seated pressure relief valve increased at elevated temperatures. The valve is required to be set to open at a pressure no greater than the maximum allowable working pressure. In Figure 7, the valve must open at 185 PSIG at 350 to 400 degrees F to prevent a dangerous overpressure situation.

The person, setting the pressure relief valve at ambient temperature, consulted the pressure relief valve catalog and found a "generic" table specifying a three percent increase in the opening pressure to compensate for the temperature differences. The person adjusted the opening pressure at ambient temperature, to 190 PSIG (185 PSIG * 103%). At the in-service temperature, the inlet pressure to open this valve is approximately 195 PSIG or 10 PSIG greater than the maximum allowable working pressure.

Even this small amount of overpressure, added to the allowable tolerances and accumulation, could have catastrophic effects on human safety and equipment integrity.

COMMON EXPECTATIONS UNSAFE

- **Manufacturers' catalogs do not always distinguish between metal-to-metal seat and soft-seat valve cold differential test pressures**
- **Users and test facility personnel conclude adjustments must be added to compensate for the temperature differences**
- **The added adjustments to the opening pressures at ambient conditions may result in the valves opening higher than the MAWP at service temperatures -- an unsafe condition**

TABLE 1

Common expectations are unsafe when it comes to soft-seated pressure relief valves in elevated temperature services.

SOFT-SEATED VALVES PERFORMED DIFFERENTLY

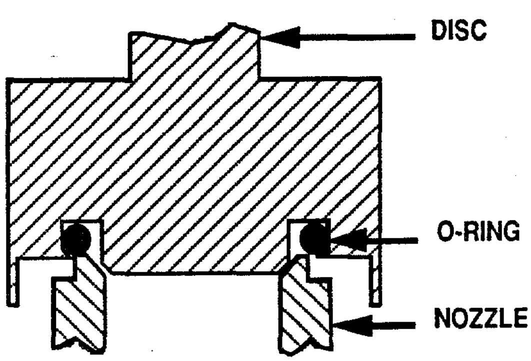

FIGURE 8

PARTIALLY RESTRAINED O-RING, SOFT-SEAT CONFIGURATION

Figure 8 is an example of a partially restrained O-Ring soft-seat configuration.

In this case, manufacturing is easier and the O-Ring has more room to thermally expand than the fully restrained configuration. On the other hand, the O-Rings have come out of the discs during in-service operations.

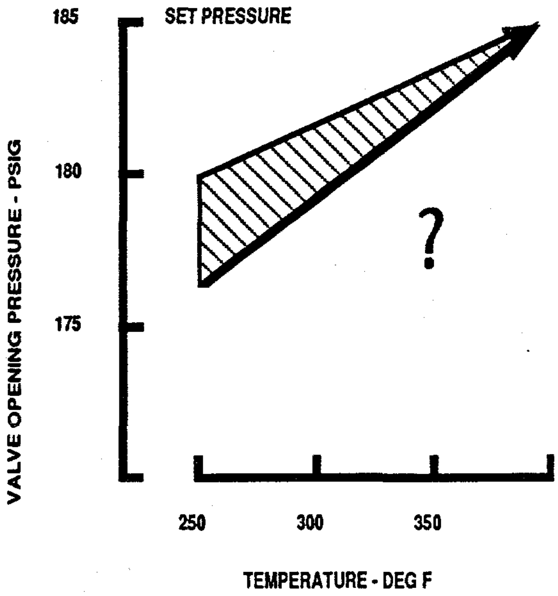

FIGURE 9

PARTIALLY RESTRAINED O-RING SEAT -- NO CHANGE IN OPENING PRESSURES AT ELEVATED TEMPERATURES

Figure 9 shows there was no change in the opening pressures during increasing temperature conditions.

It appears the decrease in opening pressure experienced by metal-to-metal seated pressure relief valves is offset by the thermal expansion of the O-Rings in these valves.

Furthermore, the partially restrained O-Ring seat pressure relief valves did not respond to the temperature increases as much as the restrained O-Ring seat valves. Apparently, the unrestrained configuration provided space for the O-Ring to expand other than only towards the nozzle, thereby, not impacting the opening pressures as much.

The tests were conducted with pressure relief valves set at different pressures to evaluate that variation. As the data show, set pressures did not alter the results.

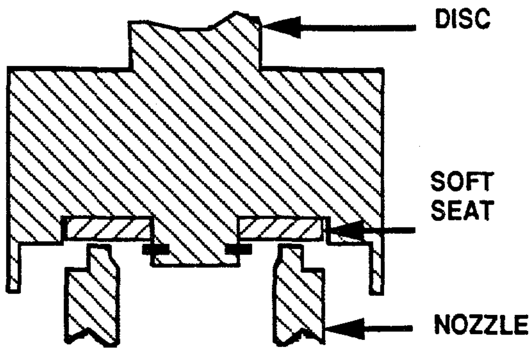

FIGURE 10

FLAT, SOFT SEAT CONFIGURATION

Figure 10 is an example of a flat, soft-seat configuration.

As with the partially restrained O-Ring, soft-seat configuration, the flat configuration is easy to machine. The flat soft seats have also come out of the discs during in-service operations.

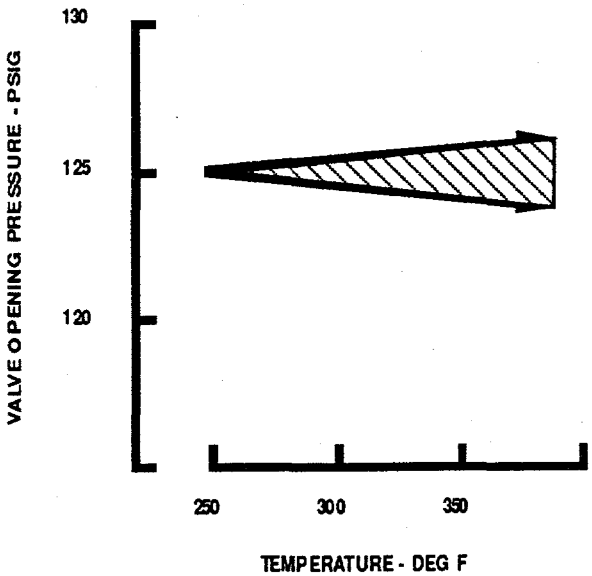

FIGURE 11

FLAT SOFT SEAT -- TYPICAL INCREASE IN OPENING PRESSURES AT ELEVATED TEMPERATURES

Figure 11 shows the typical opening pressure during increasing temperature conditions. The testing showed an increase of up to approximately two percent in the opening pressure during the temperature increases.

It appears the decrease in the opening pressures experienced by metal-to-metal seated pressure relief valves is more than offset by the thermal expansion of the flat soft seats.

NOTE: The testing clearly indicated that flat, soft-seated pressure relief valve should be set initially at the in-service temperatures. Setting the valves at ambient temperatures, even with adjustments, may not account for the soft seat material deformation at elevated temperatures.

ASME AND NATIONAL BOARD CONTACTED

The Westinghouse Electric Corporation, which operates the Savannah River Site for the Department of Energy, advised the ASME and the National Board of Boiler & Pressure Vessel Inspectors of the increase in opening pressures as the service temperature increases for certain soft-seated pressure relief valves.

In addition, the Westinghouse Savannah River Company proposed that the ASME Code be improved by requiring the manufacturers and/or assemblers to indentify the cold differential test pressures to the users and test facility personnel.

ASME CODE SECTION VIII UG-136(d)(4)

...except that valves beyond the capability of the production steam test facility either because of size or pressure may be tested on air. Necessary corrections for differentials in popping pressure between the steam and air shall be established by the manufacturer and applied to the popping point on air. ...

TABLE 2

The ASME Code [2] Section VIII UG-136 (d), "Production Testing by Manufacturers and Assemblers", presently specifies the following:

"(4) Each valve shall be tested to demonstrate its popping or set pressure. Valves marked for steam service or having special internal parts shall be tested on steam, except that valves beyond the capability of the production steam test facility either because of size or pressure may be tested on air. Necessary corrections for differentials in popping pressure between the steam and air shall be established by the manufacturer and applied to the popping point on air".

The National Board Standard NB-65, "National Board Pressure Relief Valve Repair Symbol" [3], also permits steam service valves to be set using ambient temperature air.

As specified, the manufacturers and assemblers are not required to provide the cold differential test pressure information to the users and test facility personnel. Furthermore, the requirement is directed towards steam service valves. Pressure relief valves are used in other elevated temperature services.

The ASME is presently considering making this improvement by requiring the manufacturers and assemblers to mark the cold differential test pressure on each elevated temperature service pressure relief valve. Even if the ASME does approve this improvement, it will be years before the ASME Code [2] is revised to incorporate the requirement.

USERS AND TESTERS SHOULD OBTAIN COLD DIFFERENTIAL TEST PRESSURES

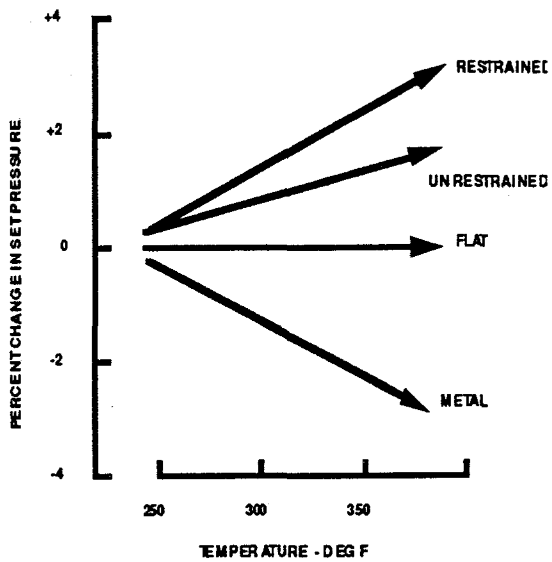

FIGURE 12

TYPICAL CHANGES IN OPENING PRESSURES FOR VARIOUS TYPES OF SEATS

Figure 12 shows the typical changes in the opening pressures of metal-to-metal seated and soft-seated pressure relief valves during increasing temperature services.

For the record, all the testing was done using saturated steam at the set pressures and ambient temperature air -- approximately 80 degrees F. This testing and the limited information from the catalogs indicated the changes in opening pressures are not totally linear with temperature increases. Therefore, manufacturers should be contacted for cold differential test pressures at specific user's conditions, including those for negative degrees F services.

The metal-to-metal seated pressure relief valve opening pressures **decreased** approximately three percent while the restrained soft-seated valve opening pressures **increased** approximately three percent. The partially restrained and flat soft-seated valve set pressures increased zero and approximately two percent, respectively.

The percentages determined by the testing conducted are not significant. Variations in pressure relief valve dimensions, materials, etc., could alter these percentages and directions. Changes in testing media could also alter the percentages and directions.

What is not changeable is that users and the testing facility personnel must be aware of the temperature impacts on the set pressures of all pressure relief valves.

Testing personnel include those doing receipt testing, scheduled testing, valve repairs, etc.

USERS AND TESTERS SHOULD

FOR SOFT-SEATED VALVES IN ELEVATED TEMPERATURE SERVICE ...

•BE AWARE OF THE TEMPERATURE IMPACT ON THE SET PRESSURES OF SOFT- SEATED VALVES

•BE AWARE THAT DIFFERENT TYPES OF SOFT-SEATED VALVES RESPOND DIFFERENTLY TO TEMPERATURE INCREASES

•HAVE THE SUPPLIERS PROVIDE THE COLD DIFFERENTIAL TEST PRESSURE AND IDENTIFY THE SOURCE OF THAT PRESSURE FOR EACH VALVE

TABLE 3

For safety reasons, users and valve testing facility personnel should be aware of the different adjustments for temperature for the metal-to-metal and soft-seated pressure relief valves. Variations in configurations and materials make significant differences in the thermal impact on the set pressure of valves. They should obtain the cold differential test pressures for each specific pressure relief valve model.

References

1. ASME PTC 25-1994, "Pressure Relief Devices"
2. ASME Boiler & Pressure Vessel Code
3. National Board NB-65, "National Board Pressure Relief Valve Repair Symbol"

Acknowledgment

All the testing was accomplished by the Harley Industries, Inc., Industrial Valve & Gage Company and Westinghouse Savannah River Company. Their efforts are acknowledged and appreciated.