Overpressure by System Design

An Oil and Gas Perspective on Safety of Kraft Digesters

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Mr. Henry is responsible for engineering consulting services in the areas of pressure relief, heat transfer, and fluid flow. He is a specialist in the design, installation, sizing, and selection of pressure relief devices and relieving systems, and has been the Chairman and Master Editor of the API Pressure Relieving System Subcommittee's Task Force on API 520 for the last 27 years. He conducts audits of pressure relieving systems to ensure compliance with OSHA, PSM legislation, and ASME, API, and DIERs Standards, Codes, and Publications. He also teaches the official API Pressure Relieving Systems course.

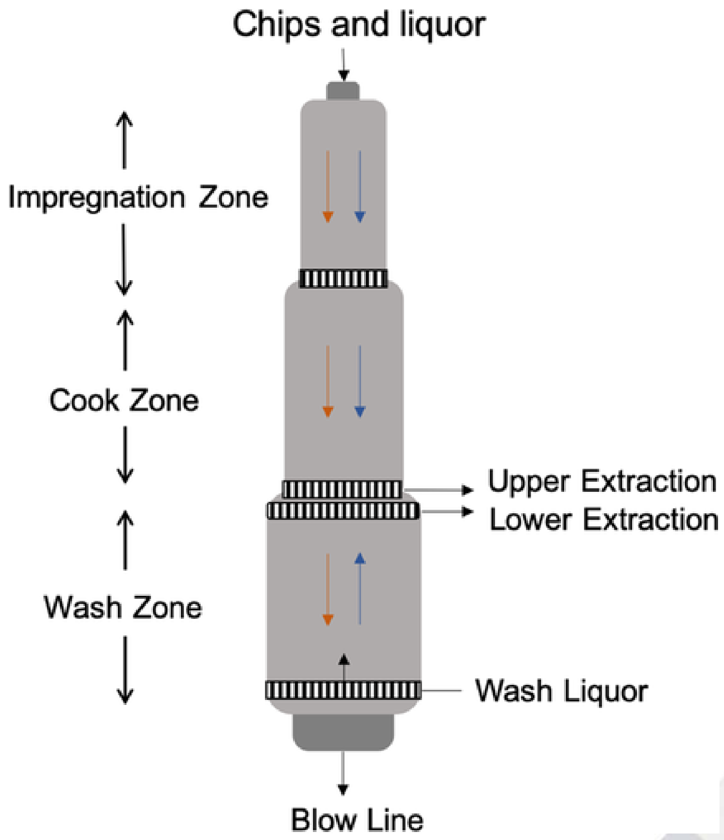
Agenda

- Introduction
- Background on Overpressure Protection by System Design
- ASME Section XIII Part 13 (UG-140) Requirements
- API 521 Approach Using Risk When Applying UG-140
- Application to Paper & Pulp Digesters
- Concluding Thoughts
- Questions and Answers

Introduction

Introduction

- Overpressure protection by system design has been used by the refiners and chemical companies for where the use of conventional pressure relief devices (PRDs) is impractical or unreliable for quite some time
- Only recently (circa 2008) has it been codified as part of the ASME pressure vessel code
- API 521 provides guidance on the application of system design (Annex E)
- System design has been used in the paper & pulp industry on kraft digesters; not all operators are applying the philosophy as intended by ASME



Introduction

- Overpressure protection by system design is covered in ASME Section VIII as well as Section XIII
- What used to be in UG-140 of Section VIII now predominantly resides in Section XIII Part 13.2
- See Non-Mandatory Appendix PP for guide to renumbering

ASME.BPCV.VIII.Div.1 (2019)	ASME.BPCV.VIII.Div 1 (2021)	ASME.BPVC.XIII (2021)
UG-125 to UG-140	UG-150-UG-156 (Reformatted and General Details moved to Section XIII per – see Nonmandatory Appendix PP for specifics)	General requirements for overpressure protection moved to this document – Specifics applicable to Section VIII, still reside in VIII.
UG-125	UG-150 (mostly translates) & UG-153	
UG-126&UG-127	UG-154	Part 3 -6 and 8-9 sections apply
UG-133	UG-152	
UG-134	UG-155	Part 3
UG-140	UG-154 (e)	Part 13
UG-140(a)	UG-154(e)(1)	Part 13.2
UG-140(a)(1)		Part 13.1
UG-140(a)(2)		Part 13.2(a)
UG-140(a)(3)		Part 13.2(b)
UG-140(b)		Part 13.3
UG-140(b)(1)		Part 13.3(a)
UG-140(b)(2)		Part 13.3(b)
UG-140(b)(3)		Part 13.3(c)
UG-140(b)(4)		Part 13.3(d)
UG-140(b)(5)	UG-154(e)(2)	Part 13.3(e)
UG-140(b)(6)		Part 13.3(f)
Non-Mandatory Appendix M	Non-Mandatory Appendix M Except: Section XIII, Non-Mandatory Appendix B is now referenced for M-5	Non-Mandatory Appendix B (for Stop Valves in Relief Systems)

Introduction

- **ASME Section VIII, Division 1 for Unfired Pressure Vessels**
  - UG-150(b) (*prev. UG-125(a)*): "All pressure vessels within the Scope of this Division, irrespective of size or pressure, shall be provided with pressure relief devices in accordance with the requirements of UG-150 (*prev. UG-125*) through UG-156 (*prev. UG-138*) (except as permitted in Section XIII Part 13 (*prev. UG-140*))."
- **API 521 – Pressure Relieving and Depressuring Systems**
  - **Role of Instrumentation in Overpressure Protection (4.2.6)**
    - Fail-safe devices, automatic start-up equipment, and other conventional instrumentation should not be a substitute for properly sized PRDs as protection against single-jeopardy overpressure scenarios. There can be circumstances, however, **where the use of PRDs is impractical** and reliance on instrumented safeguards is needed. Where this is the case, if permitted by local regulations, a PRD might not be required.
    - EXAMPLE: See ASME BPVC, Section VIII, Division 1, UG-140, Overpressure Protection by System Design. The design shall comply with the local regulations and the **user's risk tolerance criteria**, whichever is more restrictive. If these risk tolerance criteria are not available to perform analyses per the guidance in Annex E, then as a minimum, the overall system performance including instrumented safeguards should provide safety integrity level 3 (SIL-3) performance in accordance with ISA 84.01.

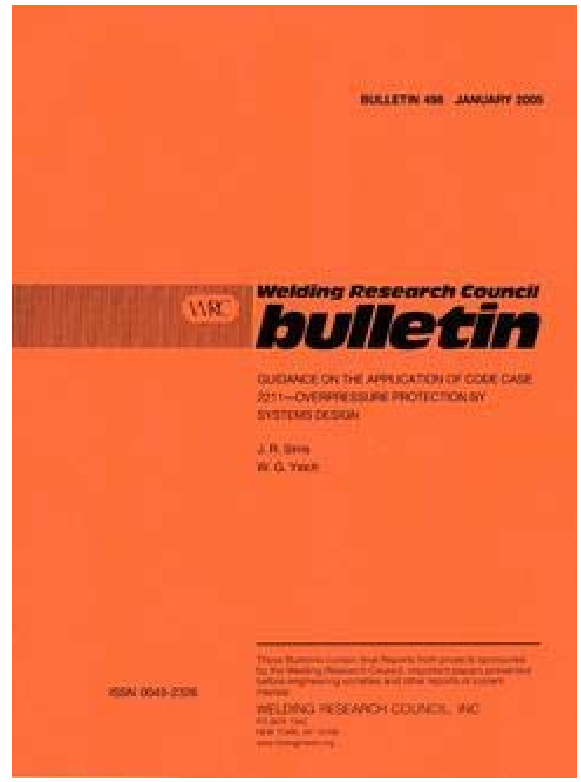
Background on Overpressure Protection by System Design

Background on Overpressure Protection by System Design

- **Overpressure Protection by System Design**
  - ASME Code Case 2211 (August 1996) gave guidance for taking credit for the presence of instrumentation or inherent safety
    - Developed jointly with ASME and API members over several years
  - Code Case 2211-1 (1999) – Reaffirmed
    - Provides an alternative to providing overpressure protection by PRD, i.e., "system design"
    - Originally, only included complete replacement of PRD ("in lieu of")
  - In 2000, ASME commissioned a study recognizing that the industry needed more guidance. Needed an approach that would promote consistency among organizations in implementing CC2211
  - WRC 498 – "Guidance on the Application of Code Case 2211-1" (2005)
  - Incorporated in the Code as UG-140 in 2008

Background on Overpressure Protection by System Design

- **Guidance from WRC 498**
  - WRC 498 – “Guidance on the Application of Code Case 2211-1” (2005)
    - Commissioned by ASME (in 2000) recognizing that the industry needed more guidance. Needed an approach that would promote consistency among organizations in implementing CC2211.
    - Provides guidelines for conducting a detailed, organized, systematic, multidisciplinary analysis to ensure that the MAWP of the vessel is greater than the highest pressure that can reasonably be expected from all **credible** operating and upset conditions.
    - Intended for use by individuals and teams skilled in the application of the methods described. Does not provide a step-by step approach.
    - Provides guidance on the use of several tools to complete the analysis and gives examples.



Background on Overpressure Protection by System Design

- **Guidance from WRC 498**
  - WRC 498 – "Guidance on the Application of Code Case 2211-1" (2005)
    - The analysis also can consider the use of instrumentation to limit the pressure.
    - Responsibility for conducting the analysis is on the user, but also notes that prior jurisdictional acceptance may be required.
    - CC2211 allows instrumentation to be used in lieu of PRDs.
      - Requires more detailed credibility assessment
      - Reliability of the instrumented system needs to be sufficient to deem the scenario as being "non-credible"
      - Defines credibility as event frequency greater than 1×10^{-5}/year
      - It is NOT sufficient to show that the instrumentation provides reliability equivalent to that of a conventional PRD

Background on Overpressure Protection by System Design

- **Guidance from WRC 498**
  - WRC 498 – “Guidance on the Application of Code Case 2211-1” (2005)
    - o WRC 498 makes recommendations to modify CC2211-1 when it is eventually incorporated into the main body of the Code.
      - Permit the pressure to increase to 110% of the MAWP to be consistent with the ASME Code normal design basis.
        - **UG-140 – allows 16% accumulation.**
      - In addition to credibility (probability), the Code should also consider consequence (i.e., risk) when assessing scenarios, as it would allow overpressure above MAWP for some low-probability but credible scenarios. CC2211 written to meet compliance (i.e., does not go over MAWP).
        - Use user’s risk acceptance criteria to establish allowable overpressures, focusing on potential vessel failure rather than probability of going over MAWP.
        - In essence, allows probability (credibility) to be greater than 1×10^{-5}/year, if consequences are sufficiently low enough. WRC 498 gives an example of what this might look like in 3.4.3.

ASME Section XIII Part 13 (UG-140) Requirements

ASME Section XIII Part 13 (UG-140) Requirements

- **Overpressure Protection by System Design**
  - Code Case 2211 was incorporated into the body of the Code as paragraph UG-140 in 2008 – now Section XIII, Part 13
  - Note that UG-140 is written for new construction
  - The decision to provide a vessel with overpressure protection by system design is the responsibility of the user
  - The user shall request that the MFG's Data Report state that overpressure is provided by system design

ASME Section XIII Part 13 (UG-140) Requirements

- **Overpressure Protection by System Design**
  - Section XIII 13.2 (prev. VIII, UG-140 (a)) states:
    - **A pressure vessel does not require a pressure relief device if the pressure is self-limiting and the pressure is less than or equal to the corrected maximum allowable working pressure (MAWP).**
    - The user shall conduct a detailed analysis to identify and examine all potential overpressure scenarios.
      - The "Causes of Overpressure" described in API STD 521 shall be considered.
      - Other more specific standards or practices may also be considered.
      - A multi-disciplined, experienced team (including operations) shall conduct an analysis using a standard methodology (e.g., HAZOP, FMECA, What-If, or equivalent) to establish that there is no pressure that can exceed the corrected MAWP.
    - The analysis shall be fully documented and signed off by the individual in responsible charge of the management and operation of the vessel.

ASME Section XIII Part 13 (UG-140) Requirements

- **Overpressure Protection by System Design**
  - Section XIII 13.3 (prev. UG-140 [b]) also states that if the pressure is not self-limiting, a vessel may be protected by system design or by a combination of pressure relief devices and system design, if the following conditions are met **(i.e., use instrumentation to eliminate scenarios OR reduce size of PRD OR eliminate PRDs altogether)**.
    - The rules below are not intended to allow for normal operation above MAWP.
    - The decision to provide a vessel with overpressure protection by system design is the responsibility of the user.
    - The user shall request that the MFG's Data Report state that overpressure is provided by system design (if no PRD installed).
    - The overpressure condition shall be readily apparent to the operators or protective instrumentation will take corrective action to prevent operation above the MAWP.

ASME Section XIII Part 13 (UG-140) Requirements

- **Overpressure Protection by System Design**
  - Section XIII 13.3 (prev. UG-140 [b])
    - o The user shall conduct a detailed analysis as described previously to identify and examine causes of overpressure (e.g., API 521).
    - o There shall be no credible overpressure scenario in which the pressure exceeds 116% of the corrected MAWP. This limit shall not exceed the test pressure.

$$MAWP_{corrected} = MAWP \times \frac{\sigma_{scenario}}{\sigma_{design}}$$

σ is the allowable stress

    - o Note that UG-140(b) requires an additional credibility assessment to be performed and points to WRC 498 for guidance.
      - **Allows (suggests) the use of risk criteria when determining credibility.**

ASME Section XIII Part 13 (UG-140) Requirements

- **Overpressure Protection by System Design**
  - Documentation shall be performed as described previously except:
    - A detailed description of any safety critical instrumentation used to limit the system pressure including identification of the independent redundancies and a reliability evaluation (qualitative or quantitative) of the overall safety system
    - An analysis showing the maximum coincident pressure and temperature from each of the scenarios

API 521 Approach Using Risk When Applying UG-140

API 521 Approach Using Risk When Applying UG-140

- **API Philosophy on Instrumentation**
  - No credit should be taken for basic process control instrumentation (BPCS) whose normal response would be to reduce the size of the relief load (however, can take credit for remaining in same position, corrected for relief conditions).
  - Take account for the response of instrumentation where normal action would increase the relief load (e.g., a flow controller will maintain an undesirable high flow by automatically opening a control valve).
  - However, with special care, redundant independent safety instrument systems (SIS) can eliminate scenarios or replace relief devices (Section XIII Part 13 [prev. VIII, UG-140]).

API 521 Approach Using Risk When Applying UG-140

- **Instrumentation to Prevent Relief Device Operation**
  - Often, shutdown systems are used to prevent relief valve from opening (layer of protection)
  - This is good engineering practice; however, **it does not replace the need for PRD capacity** (unless designed per ASME Section XIII Part 13 [prev. VIII, UG-140])
  - Prevent undesirable discharge to a flare header, scrubber, atmosphere, etc.
  - Prevent unit process upset
  - Some examples:
    - Trip heat off (steam reboiler or fired heater) to prevent overpressure on distillation process
    - Shut inlet valves or open safe vent valves on high pressure
    - Open depressuring valve in case of fire, effectively stopping the process

API 521 Approach Using Risk When Applying UG-140

- **Instrumentation When Pressure Relief Device Impractical**
  - API 521, 4.2.6 – "Fail-safe devices, automatic start-up equipment, and other conventional instrumentation should not be a substitute for properly sized PRDs as protection against single jeopardy overpressure scenarios. There can be circumstances, however, **where the use of PRDs is impractical** and reliance on instrumented safeguards is needed."
  - Some examples:
    - High level on column to prevent overfilling
    - High temperature or plugging services (PRD not suitable)
    - Trips on high-pressure turbines (upgrade trip system to HIPPS)
    - Explosion prevention to avoid large vents
    - Prevent overpressure due to mixing errors (possible explosive conditions)
    - Reduction in number and/or size of relief vents
    - Eliminate release to atmosphere
    - Chemical reactor runaways

API 521 Approach Using Risk When Applying UG-140

- **API 521 Annex E Guidance on Use of HIPS**
  - This Annex describes the use of high integrity protection systems (HIPS) in place of pressure relief devices
  - It is based on risk and ISA S84.01 (now IEC 61511), "Application of Safety Instrumented Systems for the Process Industries"
  - Emphasizes use of instrumentation to reduce the probability of an overpressure contingency
  - HIPS involve an arrangement of instruments, final control elements (e.g., valves, switches, etc.), and logic solvers configured in a manner to avoid overpressure incidents by removing the source of overpressure or reducing the probability of an overpressure contingency to such a low level that it is no longer considered to be a credible case

API 521 Approach Using Risk When Applying UG-140

- **API 521 Annex E Guidance on Use of HIPS**
  - E.2.2 provides five principal applications of HIPS
    - To eliminate a particular overpressure scenario from the design basis
    - To eliminate the need for a particular relief device
    - To provide system overpressure protection where a relief device is ineffective
    - To reduce the probability that several relief devices will have to operate simultaneously, thereby allowing for a reduction in the size of the disposal system
    - To reduce the demand rate on a relief device, consequently reducing the risk

API 521 Approach Using Risk When Applying UG-140

- **API 521 Annex E Guidance on Use of HIPS**
  - Benefit of HIPS
    - Cost effectiveness
      - Eliminate the need for costly upgrades to existing flare system
      - Reduce the size of new relief/flare system
      - Smaller and fewer PRDs
    - Higher level of availability/reliability
      - Lower failure to danger rates
      - Designed primarily to fail safe
    - Can be used in concert with relief devices (where PRDs are the back-up)
  - Disadvantages of HIPS
    - Ongoing costs can be high with routine testing versus routine maintenance of PRDs – costs rise disproportionately to safety integrity level (SIL)
    - Inadvertent trip can cause a major shutdown or operational upset

API 521 Approach Using Risk When Applying UG-140

- **API 521 Annex E Guidance on Use of HIPS – Requirements (E.3.3.2)**
  - General steps to follow in using SIS to protect against a process hazard are broken down as follows:
    - Perform a PHA (LOPA is often used) to identify hazards
      - ISA does not specify method; WRC 498 requires a multi-discipline team using WI, ETA, HAZOP, FTA, FMEA, etc.
    - Apply non-SIS protection layers to eliminate or reduce risk
    - Determine if an SIS is needed to reach risk target
    - Define a target SIL or target-availability value for the SIS (SIL-1, 2, or 3)
      - Note that a high SIL is not always needed; for example, one redundant transmitter may be all that is needed

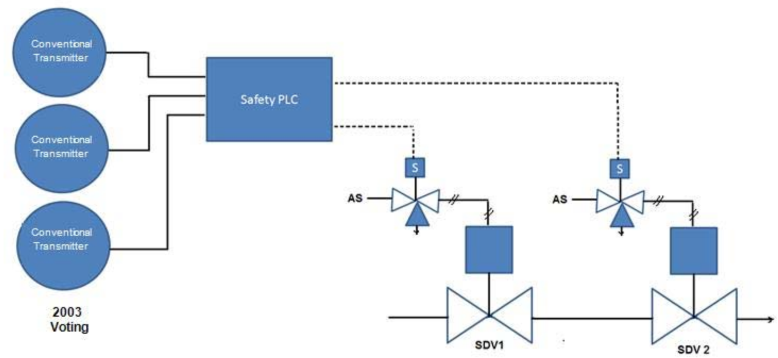
API 521 Approach Using Risk When Applying UG-140

- **API 521 Annex E Guidance on Use of HIPS**
  - Application of SIL requirements per ISA 84.01 (E.3.3.3)
    - Select appropriate SIL or actual availability (note that an SIL-3 may require 2 out of 2 sensors, 2 out of 3 voting logic, and redundant valves

Safety Integrity Level (SIL)			SIS Performance Requirements	
ISA S84.01	IEC 61508	DIN V 19250 (TUV) Class	Safety Availability Required (%)	Average Probability of Failure on Demand
1	1	1 and 2	90 to 99	10^{-1} to 10^{-2}
2	2	3 and 4	99 to 99.9	10^{-2} to 10^{-3}
3	3	5 and 6	99.9 to 99.99	10^{-3} to 10^{-4}
--	4	7	> 99.99	$< 10^{-4}$
--	5	8	> 99.999	$< 10^{-5}$

    - Design SIS to meet the selected SIL
    - Perform availability calculations to verify integrity
    - Specify testing intervals to maintain system availability or SIL
    - If appropriate, perform Management of Change procedures

API 521 Approach Using Risk When Applying UG-140



- **API 521 Annex E Guidance on Use of HIPS**
  - **HIPS Availability Analysis (E.4.4)**
    - Forces us to analyze sensor quality and availability
    - May need to increase level of diagnostic to reduce failure possibilities
    - Increase redundancy (e.g., SIL-3 system requires redundant transmitters, logic units, and redundant control valves or solenoids)
    - Use diverse components (e.g., DP level transmitter, conductivity probes, capacitance probes, nuclear device)
    - May need to increase testing frequency; HIPS reliability is directly related to testing frequency
      - Consider the capability of site to carry out the tests
      - Testing as a process has the potential for introducing faults and spurious shutdowns due to human error. Design the system with the desired availability with a minimum of off-line testing

Application to Paper & Pulp Digesters

Application to Paper & Pulp Digesters

- Paper & pulp industry needs to ensure that they are following the requirements of Section XIII, Part 13 (UG-140). Each installation where system design philosophy has been applied should be audited to ensure that the requirements of UG-140 are met.
  - Questions that should be asked:
    1. Has permission from the jurisdiction to use system design been obtained?
    2. Does the installation using a system design approach pass the “impractical” hurdle? Instrumentation should not be used in lieu of a PRD when the installation of a traditional PRD is reasonable.
    3. Where inherent safety has been established (UG-140a), has a multi-disciplined team been involved in analyzing potential overpressure scenarios in accordance with API 521, and has it been established that there are no credible overpressure scenarios that could possibly overpressure the digester above its MAWP?
    4. Where instrumentation is used as a replacement for PRDs or in combination with PRDs (UG-140(b)), has a multi-disciplined team been involved in analyzing potential overpressure scenarios in accordance with API 521, and has it been established that there are no credible overpressure scenarios that could possibly overpressure the digester above its MAWP by more than 116%?
    5. Additionally, has a qualitative or quantitative credibility assessment been completed by qualified individuals to demonstrate that the probability (or credibility) of any overpressure event meets the corporate risk criteria?

Application to Paper & Pulp Digesters

- Paper & pulp industry needs to ensure that they are following the requirements of UG-140. Each installation where system design philosophy has been applied should be audited to ensure that the requirements of UG-140 are met.
    - Questions that should be asked:
        6. Where SIS has been used as part of the system design to eliminate or reduce the size of PRDs, has a reliability (or availability) analysis been completed per IEC 61511?
        7. Was the calculation of overpressure for credible scenarios compared against the “corrected” MAWP, or 116% of the corrected MAWP, as applicable?
        8. Have the results of the system design studies been documented in accordance with UG-140 and signed by the individual in responsible charge of the management and operation of the vessel?
        9. For safety critical equipment, have test intervals and test protocols been established so that the required reliability (or required SIL level) as determined from the reliability analysis is maintained? Does the facility receiving the SIS have the skills and resources to operate and maintain the system?

Final Thoughts

Concluding Thoughts

- Most likely certified relief devices will continue to be the standard means of overpressure protection
- There will be applications where PRDs will not be reliable or practical; use of UG-140 will be rare but necessary
- Installations can be improved when risk and instrumentation are an integral part of overpressure protection analysis
- Be aware that XIII, Part 13.3 (UG-140b) may not require a high SIL; however, in the majority of HIPS cases, either SIL-2 or SIL-3 will be required
- Low-risk installations using Annex E guidance may show that no safeguards are required to meet companies' risk criteria; caution is warranted
  - Do not use Annex E to eliminate PRDs where no safeguards are present or BPCS are available (should pass the "impractical" test), even if risk assessment shows none needed
  - We still cannot operate above MAWP, even if the risk is low
- Instrumentation may be more expensive than standard PRD protection, although costs have come down

Questions and Answers