

EVALUATION AND ACCEPTANCE CRITERIA SYNTHESIS FOR ASME SECTION VIII VESSELS AND B31.3 PIPING SUBJECTED TO SLUG LOADING

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ABSTRACT

A program has been underway to improve the tolerance for two-phase flow slug loading on separator pressure vessels and inlet piping systems at operating oil field processing facilities. Elements of the program plan focused on the tailoring of industry standards to establish realistic and reliable evaluation and design criteria which provide consistent margins of safety for all elements of the systems. This paper presents the bases and development of the evaluation and acceptance criteria for the coupled pressure vessel and piping systems. Central to the evolution of this criteria was the fatigue analyses undertaken to conform with the requirements of ASME Section VIII, Division 2 for the vessels and with the intent of ASME B31.3 for the piping. The paper demonstrates the compatibility between the design by analysis methods of Section VIII, Division 2 and the more empirical methods of ASME B31.3. Suggestions are offered that might enhance the future compatibility of pressure vessel and piping design rules.

INTRODUCTION AND BACKGROUND

Two-phase flow slug loading on the inlet systems of the oil field processing facilities at the Kuparuk River Unit, North Slope, Alaska has been the subject of recent, careful consideration by ARCO Alaska, Inc. This has been made necessary by higher than anticipated oil production rates from the field, which in turn has resulted in larger flow rates of oil, gas, and water mixtures.

Under stratified conditions the flow in a pipeline is well-behaved, with liquid flowing at one velocity in the bottom of the line and gas flowing at a higher velocity above the liquid.

Elevation changes or other sources of flow disruption in the pipeline can cause liquid holdup, or blockage of the gas flow by liquid "plugs". The higher velocity gas behind the liquid accelerates the liquid plug and a "slug" results. Slugs have varying lengths, densities, and configurations. At each change in direction of flow, a resultant force must be resisted by the piping and pipe support system. Unrestrained elbows and branch connections in piping networks are subjected to varying loads causing cyclic stresses. Similarly, vessel nozzles are subjected to cyclic stresses and fatigue damage. Vessel internals can also be impacted by these dynamic fluid forces. To mitigate these effects the criteria described herein have been used to upgrade the Kuparuk inlet systems to meet the increased demands.

The upgrade program employed a variety of hardware modifications to enhance fatigue performance. They included reinforcements or replacement of vessel nozzles, sleeving or otherwise reinforcing highly stressed piping components (e.g., reinforcements to components such as elbows and branch connections), replacement of pipe spools, reinforcement or addition of pipe supports, and the reinforcement of existing or the addition of new pipe support structures. While it is true that each element of the inlet systems was initially designed and supplied in accordance with industry standards, the design conditions (e.g., the loads) specified did not include such severe slug loading as those which were being experienced as the result of the higher than anticipated production. The engineering approach used was to design modifications of the integrated systems using better loading definitions and synthesized acceptance criteria, particularly for the pressure boundary elements, in order to establish balanced designs.

With a realistic estimate of the systems' responses to slug loading of given magnitudes and frequencies of occurrence, the synthesized acceptance criteria can be invoked to establish whether or not modifications of a particular complexity would be prudent. However, reliable mechanistic means do not currently exist to predict, with certainty, realistic values of the slug loading magnitudes and their frequencies of occurrence. Hence, on-line monitoring systems have been installed and operating for nearly a year. The real-time monitoring of the facilities is the most logical and most cost-effective means of assembling key information needed as input for responsible decisions regarding hardware modifications. These systems are also being used to explore means to reduce the severity of the slug loading by changes in operational parameters and controls. The reader can gain additional insight as to how these on-line monitoring systems fit into the overall program from the paper titled "Program for Improving Multi-Phase Flow Slug Force Resistance at Kuparuk River Unit Processing Facilities" (Reference 1).

INTEGRATED SYSTEMS EVALUATION METHODS AND SLUG EQUIVALENT STATIC LOADS

The inlet systems consist of various diameter flow lines (12 to 24 inch diameter) tying into inlet manifolds (30 or 36 inch diameter), each of which flows into the inlet nozzle of a 15 foot diameter separator vessel. The vessels were designed for internal pressures of 150 psig. The inlet manifolds are housed in crude oil inlet modules (buildings). The separator vessel inlet nozzles are located outside and on top of the vessels, 30 to 50 feet above grade. The inlet lines vary from approximately 100 feet to more than 300 feet in length. Figure 1 illustrates a typical inlet system and Figure 2 provides photographs of that same system.

The flow lines from the drill sites are above grade and are supported on pipe rack structures. Some anchors and guides were incorporated in the original designs, but the flexible steel support structures allow considerable flow line movement when subjected to severe slug-induced forces. The inlet manifold systems are supported by the inlet module structures, but these have likewise proven to be less than adequate to limit slug-induced movements. The inlet manifolds terminate at the separator vessel inlet nozzles. Changes in direction of flow in the manifolds immediately upstream of the vessels and the lack of supports caused significant axial loads, shears, and bending moments to be introduced into the vessel shells at the inlet nozzles. Additional forces are introduced into the vessel shells by attached internals intended to divert the flow entering the vessel.

Figures 3(a) through 3(e) show an idealization of the problem. If flow conditions which could result in severe slug loading had

been postulated during the original design, it is likely that a conservative value for the force R would have been specified. For steady flow conditions, a comparative force can be computed from momentum considerations and a load factor could have been applied to account for the transient nature of the flow. Design and operating pressures and the numbers of pressure cycles would have been appropriately specified for the piping systems and the vessels. The design of the piping and the locations of pipe supports would probably have been selected using traditional, proven piping design practices. Simple statics would have been applied to establish reaction loads for which the system support structures would have been designed. Likewise, nozzle reaction loads would have then been developed using similar methods and included as part of the vessels' design specifications.

Few would have questioned that the design of each individual element was conservative, even though no focused effort would have been undertaken to understand how conservative one class of elements (say, the piping) was relative to the other classes of elements (i.e., the vessel nozzles, the pipe supports, or the system support structures). Because the systems considered in this work were already built and in operation, more refined evaluation methods were employed. Also, since a major issue was related to the fatigue resulting from a range of dynamic loading magnitudes and frequencies, the concept of expressing the fatigue resistance of the various mechanical and structural elements in terms of slug equivalent static loads was introduced.

Why An Integrated Approach Is Needed

The inlet piping systems at each of the facilities are complicated. The pipe size is both large and varying. The piping layouts are different at each facility and they have numerous branches, bends, and other flow restrictions.

In addition to the variety of the pipe components and the routing, pipe supports and the associated support structures include a wide spectrum. Nearly all of the original supports were intended to act mainly as gravity supports. While most piping was supported to accommodate some lateral loads, the systems were not, in general, originally designed to withstand severe slug loading.

As noted, all inlet piping flows into the inlet manifolds. These inlet manifolds are routed to the separator vessels and they mate to inlet nozzles of the same diameter. They are large nozzles for vessels the size of these separator vessels (i.e., 30 inch or 36 inch diameter nozzles in 15 foot diameter vessels) and the slug loading in the piping systems can produce large reaction forces on the nozzles. The original designs of the separator vessel nozzles made no provision for reaction loads from severe slug loading on the attached piping.

