INVESTIGATION OF PROTECTION MEASURES AGAINST WATER HAMMER IN THE JETTY TANK FARM OF INEOS GRANGEMOUTH

Project Overview

INEOS Grangemouth currently faces a problem with fluid pressure transients, called water hammer, in its B-Cut export line. The high system design flow accompanied by low operating pressure results in pressures exceeding the allowable limits when instantaneous valve closure occurs, such as in the case of an emergency shutdown.

In the current research both manual and computer simulation methods have been used to predict the magnitude of the pressure transients at various points in the B-Cut export lines. Computer simulation has also been used to explore various actions for reducing the magnitudes of the pressure transients in the pipeline.

Project Objectives

- Determine the magnitude of transient events occurring in the B-Cut system at INEOS Grangemouth.

The existing system was analysed for worst case scenarios. The maximum static pressure along the pipeline from the Jetty Tank Farm to the loading ship was calculated. Unbalanced forces on the pipework at specific locations were also investigated. A comparison between numerical results generated by a computer program and a manual method was undertaken to validate the accuracy of the results.

- Determine if the bladder-type accumulators are correctly positioned and sized.

A comprehensive review of a transient analysis of the system was done. Data of the pressure in the bladders for the period 29/06/2015 to 29/12/2015 was recorded. Failed bladders were examined to find any mechanical faults.

- Provide the asset with a feasible solution, both operationally and financially, to solve the problem of the failed surge accumulators.

A proposed plant modification was suggested. Different strategies to protect against excessive surge pressures were evaluated. The strategies were fully compared and the overall cost of the modifications to the plant was estimated.

Brief Description of the System

Benzene concentrate (B-Cut) produced on the Grangemouth site is exported to customers by ship over the east jetties including Jetty 2 and Jetty 3. The ship loading is based on pumping B-Cut to Jetties 2 or 3 to load a 2400 tonne vessel in 10 hours.

The ship is connected to the mild steel shore side pipework by a length of heavy duty flexible hose which is the final link in the transfer system over the water of the dock. It is recognised that the hose represents the weak point of the system, in terms of containment of the product. Protection against excessive system pressure is provided in the form of bladder-type surge accumulators. Over the years in which they have been in operation the bladders have shown a tendency to split in service and lose their pre charge pressure. This has the effect of eliminating the protection system which is designed to maintain the integrity of the flexible hose and puts at risk the environmental performance record of the ship loading operation.

Loading arms   Surge accumulators   Burst bladder

Figure 1: Important features being investigated in this project

This project aims to investigate why this method of protection against water hammer continues to fail. Plant Modifications are suggested to solve this problem.

AFT Model of the System

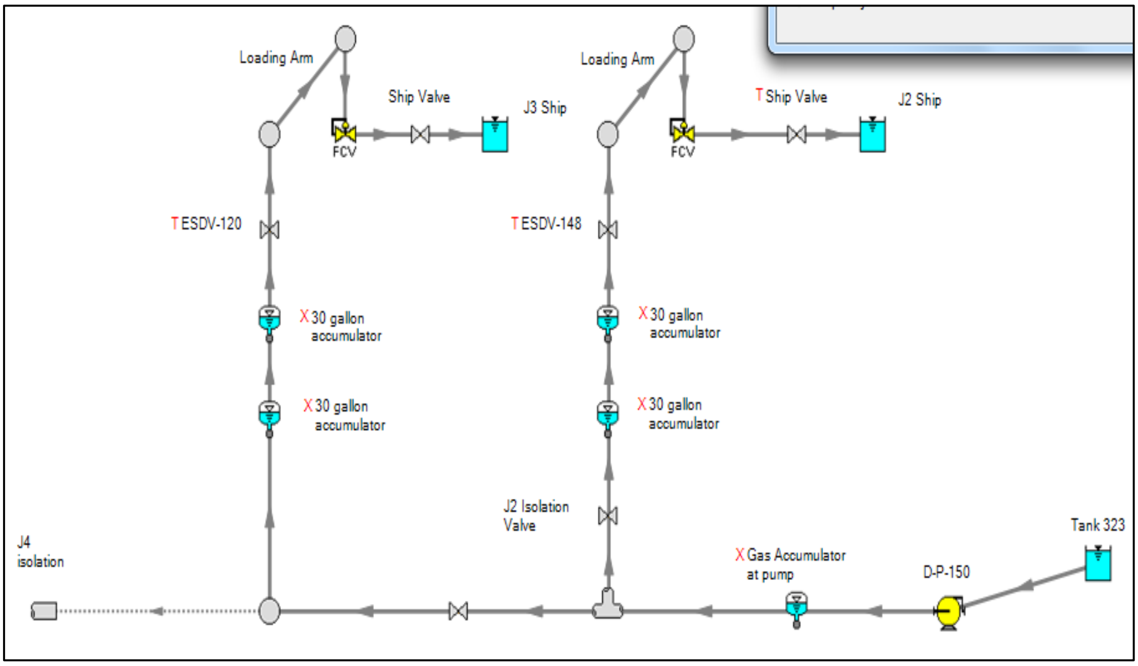

Figure 2: Base model constructed in AFT Impulse 5

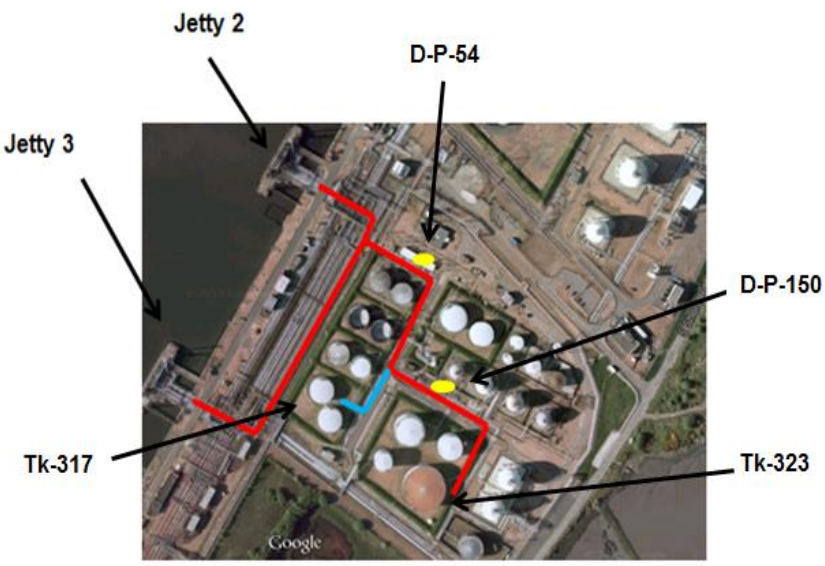

Figure 3: Transfer of B-Cut from loading tanks to ships

Overview of Computer Simulations

In the following section, Case 1 describes the analysis performed for ship valve closure. This provides information on the worst case scenario for transient events. This is followed by Case 2 in which an Emergency Shut Down (ESD) situation is modelled; this being a more common scenario. Cases 3 and 4 describe modifications to the plant which are intended to ameliorate the worst effects of the transient conditions.

Case 1: Ship Valve Closure

<u>Introduction</u>

The aim of the simulation was to determine whether the maximum pressures experienced when the ship valve closes exceed the piping pressure ratings for the system.

<u>Description of Simulation</u>

The ship shutdown valve is taken as an 8 inch gate valve with a 15 s stroke. Although the total closure time of the ship valve is assumed as 15 s (compared with 5s for the ESDV), the effective closure time of this valve is, in fact, shorter than the ESDV. This difference in effective valve closure time arises since the ship's valve has been taken as a gate valve whilst the ESDV is a ball valve.

Transient analysis performed using AFT Impulse indicates a maximum pressure peak of 26.5 barg. This maximum pressure is significantly higher than the allowable pressure in the loading arm hose. Furthermore, the pipeline surge overpressure allowance of 25.5 barg is exceeded. From this analysis it is clear that ship valve closure leads to unacceptable conditions in the system. Assuming an initial bladder pre charge of 4.8 barg (ideal conditions), the maximum static pressure output data is large enough to over compress the bladder in the accumulator and render this surge protection useless. This problem arises because gas accumulators cannot withstand compression ratios higher than 4:1.

<u>Discussion of Ship Valve Closure Results</u>

Comparison between the magnitude of the initial surge pressure resulting from a rapid valve closure on Jetty 3 and Jetty 2 show the maximum static pressure is independent of the pipe length. The length only influences what is meant by a "rapid" valve closure. The Joukowsky equation is applicable in this case since the ship valve closes in less time than the pipe period for both Jetty 2 and Jetty 3.

Case 2: Closure of ESDV-120 during Ship Loading

Introduction

The aim of the simulation is to investigate the effects a slower valve closure time than in Case 1 has on the pressures experienced throughout the system.

Description of Simulation

Quick closure of ESDV-120 causes a water hammer event to be initiated with a pressure rise similar to that in the ship valve closure case (Case 1). This pressure rise is transmitted back and forth through the export line. Firstly, the rise in pressure at the ESDV - peaking at 17.7 barg - is experienced at the head of Jetty 3 and the loading lines that run along the dock side, as well towards Jetty 4, wherefrom the flow is transmitted back northwards to the loading pump. This means that a transient pressure gradient now exists in both directions. Thus some flow is accelerated towards Jetty 4 and this is subsequently arrested at the closed isolating valve. A secondary pressure rise is then generated which is proportional to the change in velocity and the wave speed.

Similarly, the pressure gradient is also accelerated back towards the loading pump and this impinges on the closed non return valve (NRV). A complex pattern of pressure waves is therefore established between Jetty 3, Jetty 4 and the loading pump and these summate to increase the peak pressure to 18.4 barg at Jetty 4.

Discussion of ESDV-120 Closure Results

The extended closure time of ESDV-120 results in a significant decrease in the maximum surge pressure experienced (17.7 barg) compared with the maximum surge pressure experienced (26.5 barg) where the shorter ship valve closing time is used. Unlike in Case 1, here the pipeline overpressure allowance is not exceeded. This is because the ship's valve is modelled as a gate valve whilst the ESDV is modelled as a ball valve with both having different closure characteristics.

Analysis of the effects of ESDV-120 closure performed using AFT Impulse 5 confirmed that when the effective valve closure time extends over the pipeline period the maximum theoretical Joukowsky head is not developed. However, the flexible loading arm hose would still experience pressures over and above the maximum allowable surge pressure and therefore would be at risk of failure.

As a result of both ship valve closure and ESDV-120 creating excessive surge pressures in the B-Cut export line (investigated in Case 1 and 2), methods of surge suppression are examined in Cases 3 and 4.

Case 3: Loading Rate Calibration

Introduction

Case 3 describes a calibration study which was undertaken with the aim of finding out how much the loading flow rate should be reduced to avoid the surge pressure in the loading hose from exceeding the hose pressure rating. This study applies to the Emergency Shut Down scenario (Case 2) only, which gave a surge pressure of 17.7 barg at the loading arm hose.

Description of Simulation

This calibration study confirms that the peak surge pressure in the loading hose is reduced below the 13.8 barg surge rating if the loading rate is limited to 165 tonnes per hour.

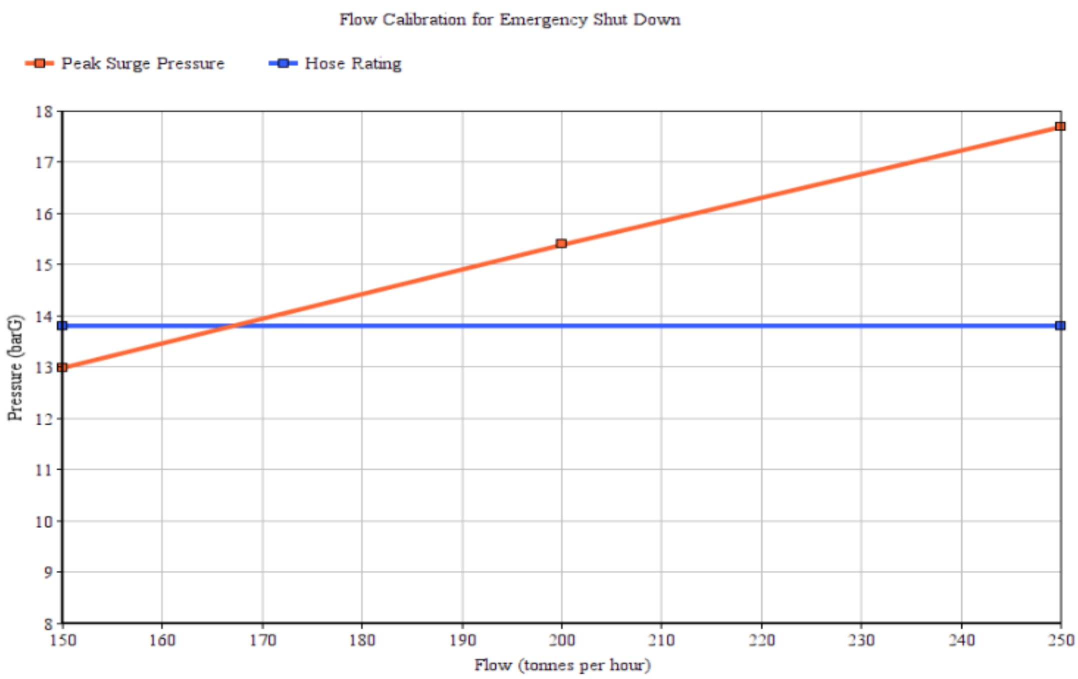

Figure 4: Graph of peak pressures in loading hose

Discussion of Loading Rate Calibration

From Case 3, it is demonstrated that surge pressures at the Jetty head would be reduced with a reduction in flow rate through the B-Cut export line to the ship. Furthermore, the existing ESD system would not require surge protection and so the surge accumulators could be removed if the maximum ship loading rate is restricted to 165 tonnes per hour based on B-Cut being pumped via D-P-150.

Case 4: System Analysis with Gas Accumulators

Introduction

Cases 1 to 3 did not include the effects of the accumulators in damping down surge pressure so that the "base" cases could be established. In this case the accumulators are on-line. All other conditions are unchanged from Case 2.

Jetty 3 contains three accumulators, two 150L in size and one 95L. Both 150L accumulators have a design pressure of 14.5 barg. The 95L bladder is currently not endorsed.

Description of Simulation

Ship Valve Closure with Accumulators

- HYDAC supply **49 gallon** capacity surge accumulators which produce maximum pressures of **10.1 barg** at the Jetty head. A **2 barg pre charge pressure** would result in an ineffective form of protection.

ESD with Accumulators

- The existing accumulators (**30 gallon**) can just protect the system when pre charged to **4.8 barg**. However at **3.5 barg (the current level)** the bladders will burst.

The INEOS B-Cut system which operates at a low pressure of 6 barg does not allow much margin for pressure drops in the nitrogen pre charge pressure before the compression ratio of the bladder is at risk.

Discussion of Gas Accumulators Protection Measure

It is shown that peak surge pressures towards Jetty 3 are reduced by utilising the accumulators. However, the loading arm hose has a surge rating of 13.8 barg hence the accumulators would not successfully protect against unwanted transient events in the case of ship valve closure or ESDV-120 closure if the pre charge pressure in the bladders is at the current level of 3.5 barg.

The transient analysis performed in Case 4 demonstrates that the value of the accumulator's pre charge must be kept above 4 and 4.5 barg in order to effectively mitigate surge pressures for the ESD scenario. On the other hand, for ship valve closure the existing bladder-type surge accumulators cannot mitigate surge pressures at any pre charge level and so larger accumulators are required on-line. By installing two HYDAC bladder-type surge accumulators with 49 gallons capacity (to replace the existing 30 gallons capacity) the bladders in the accumulators are able to withstand pressure drops to a level of 2.8 barg in the ESD scenario and 2.0 barg for ship valve closure before the bladders would collapse. As a result, this method of protection would work for both ship valve closure and ESD scenarios and is a proposed solution to the problem currently being experienced.

Why a Complete Transient Analysis Using a Computer Package is an Essential Part of Investigating Water Hammer Protection Methods

The use of AFT Impulse 5 is justified because it emphasises just how important it is to be able to perform a complete hydraulic transient analysis. If the designer were to rely on the manual methods in the form of the Joukowsky equation followed by using an accumulator sizing program such as the HYDAC Accumulator Sizing Program, then the bladders with correct pre charge would appear to be sized correctly. When different conditions are investigated such as a drop in pre charge levels, the effect of the protection can in fact worsen the transient conditions experienced throughout the system. This highlights the importance of using an advanced computer package in the analysis stage of pipeline design.

Conclusion

The following conclusions can be drawn from the current research:

- AFT Impulse 5 software can be used to predict accurately transient fluid pressures in the INEOS B-Cut export line. The results obtained from AFT Impulse 5 were partially verified using a manual method involving the Joukowsky equation although such a method is only viable under certain limited conditions.
- AFT impulse 5 proved to be a powerful tool for investigating a range of potential solutions for ameliorating pressure transients in the B-Cut line.
- When pre charge levels for the existing accumulators were set at 4.8 barg the 30 gallon accumulators would cope with the excessive surge pressures in the ESD scenario. Installing two new 49 gallon accumulators allowed the pre charge levels in the accumulators to drop significantly before bladder failure would be encountered. Improved maintenance of the bladder accumulators will help to reduce costs associated with replacing bladders whilst installing pressure gauges on the Jetty 2 accumulators will make maintenance easier to perform.
- Reducing the flow rate to 165 tonnes per hour would minimise surge effects but this would increase loading times substantially and is therefore not viable on economic grounds.
- Replacing export line pipes with larger pipes would resolve the surge problems, but the cost of replacement would rule this option out in the short to medium term. These surge problems would also be mitigated by changing the flexible loading hose to a full hydraulic loading arm but this would be an expensive option.
- Surge transient pressures could also be reduced by installing a 100 gallon surge tank on each jetty. However, this option is likely to involve difficulties in installation (installing a large tank in a small area) and considerable cost.
- Protecting against the most severe problem of water hammer in the system can be achieved by adding a second level of ESD protection. Minimal modifications to the system would be required but in return the worst case scenario of hydrocarbons being released to the atmosphere will be prevented.

Future Work

With respect to fluid transients, the evaluation of risks is quite complex and requires an element of engineering judgement. The primary reason for this arising is because no two systems are really quite the same, so problems that can occur, and the practical steps to overcome them, differ from one system to another. At some point in the future, most likely some distance away, there will be programs developed that will “design” rather than merely “analyse” predetermined systems. There are no papers on this issue, but by combining human expertise, judgement and discretion in a computer system along with the theory already in place, the analyst’s input whilst analysing fluid transients may be required upon less.

A Quick Thanks to AFT

I would like to take this opportunity to thank AFT as a company for being so responsive and helpful. The software provided to me (AFT Impulse 5) has helped me to make the transition from academia to the professional world. The software has played an important role in the completion of my MEng project at the University of Glasgow and for that I am grateful. INEOS, the company I completed this project for, were very impressed with the full set of results I was able to produce using the software provided. Furthermore, suitable plant modifications were analysed and fully compared which enabled numerous options to be provided to the asset at INEOS Grangemouth to ameliorate the excessive pressure transients.