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Complex Flare Network Analysis – Best Practices

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ABSTRACT:

Many petrochemical companies are currently engaged in flare systems review and upgrade projects. They wish to ensure continuing safe operations, to maximize the use of their existing flare systems, and to minimize the need for modifying existing flare structures or building new ones.

This presentation summarizes the stages involved in a comprehensive flare systems evaluation, outlines the design criteria to be addressed, and provides guidance on best practices for this vital part of a plant's safety systems.

A case study involving a complex flare network is also presented.

Keywords:

Flares, Headers, Emergency Relief Systems

1. INTRODUCTION:

A primary component to help ensure the mechanical integrity of any refinery or petrochemical plant is a well-designed pressure relief system, typically comprising multiple pressure relief valves connected to a flare system. The pressure relief valve ensures mechanical integrity of equipment by opening at a specific pressure, during an overpressure situation, thereby preventing a rupture of the equipment. The flare system then safely disposes of any potentially hazardous fluid vented during the overpressure scenario, by separating the liquids and vapors, and burning the vapors from a flare stack.

The BP Texas City incident in March 2005 demonstrated the catastrophic consequences that can result from an improperly designed effluent handling system. Recommendations made by the US Chemical Safety Board following their incident investigation now have many petrochemical companies currently engaging in reviews of their effluent handling and flare systems. They wish to ensure continuing safe operations, to eliminate hazardous atmospheric releases, to maximize the use of their existing flare systems, and to minimize the need for modifying existing flare structures or building new ones.

2. FLARE SYSTEMS ANALYSIS METHODOLOGY

Broadly speaking, a flare systems analysis can by summarized in the main points below:

- Establish Global Overpressure Scenarios
- Verify Relief Device Capacity
- Construct Flare Networks Model
- Analyze Flare Systems Hydraulics
- Assess Design Checks and Resolve Deficiencies
- Re-analyze Flare Systems Hydraulics

2.1 ESTABLISH GLOBAL OVERPRESSURE SCENARIOS

Global overpressure scenarios must be established for any situation which could result in simultaneous relief device discharges. Typically these scenarios are caused by failure of a utility system such as electric power (partial or total) or cooling water. Other typical potential causes could be instrument air failure or fire. The global fire flaring load is typically determined by imagining a fire circle zone based on API STD 521 (7.1.2) which can vary in size between 232 m^2 (2500 ft^2) to 464 m^2 (5000 ft^2), though this usually is not the worst case flaring load event.

When developing global scenarios, basic process control systems (BPCS) and safeguards should be considered to establish a credible event. For example, credit can be given for some failure positions of control valves per API STD 521 (7.1.4.3). Credits or debits for other properly designed safeguarding systems may also be considered, as well as the potential for cascading failures.

The product of this review should be a list of all the individual flare loads for each global scenario including relief devices, control valves, depressuring valves, etc. This will allow the establishment of a design flare load base case.

2.2 VERIFY RELIEF DEVICE CAPACITY

For a Flare Systems Analysis to be successful and accurate, it is imperative to have accurate data for all the relief devices which tie in to the flare. To complete the global scenario assessment, flow capacity information for different relief device contingencies is required.

It is highly recommended that the Flare Systems Analysis include a review of the individual relief device design basis calculations. Depending on the age of the plant and quality of the relief systems documentation, this information may be incomplete or lacking for existing facilities. If the documentation is found to be insufficient, then proper documentation of the relief device design basis should be done before proceeding with the Flare Systems Analysis. Other aspects that need to be considered when verifying the flows include:

- Multi-component representation of stream compositions
- Device inlet and outlet piping configuration
- Relief device flow and opening characteristics for accurate representation of peak flow
- The presence of multiphase, supercritical, high-viscosity, and/or reacting flows
- Condensation
- Multiple choke points

2.3 CONSTRUCT FLARE NETWORKS MODEL

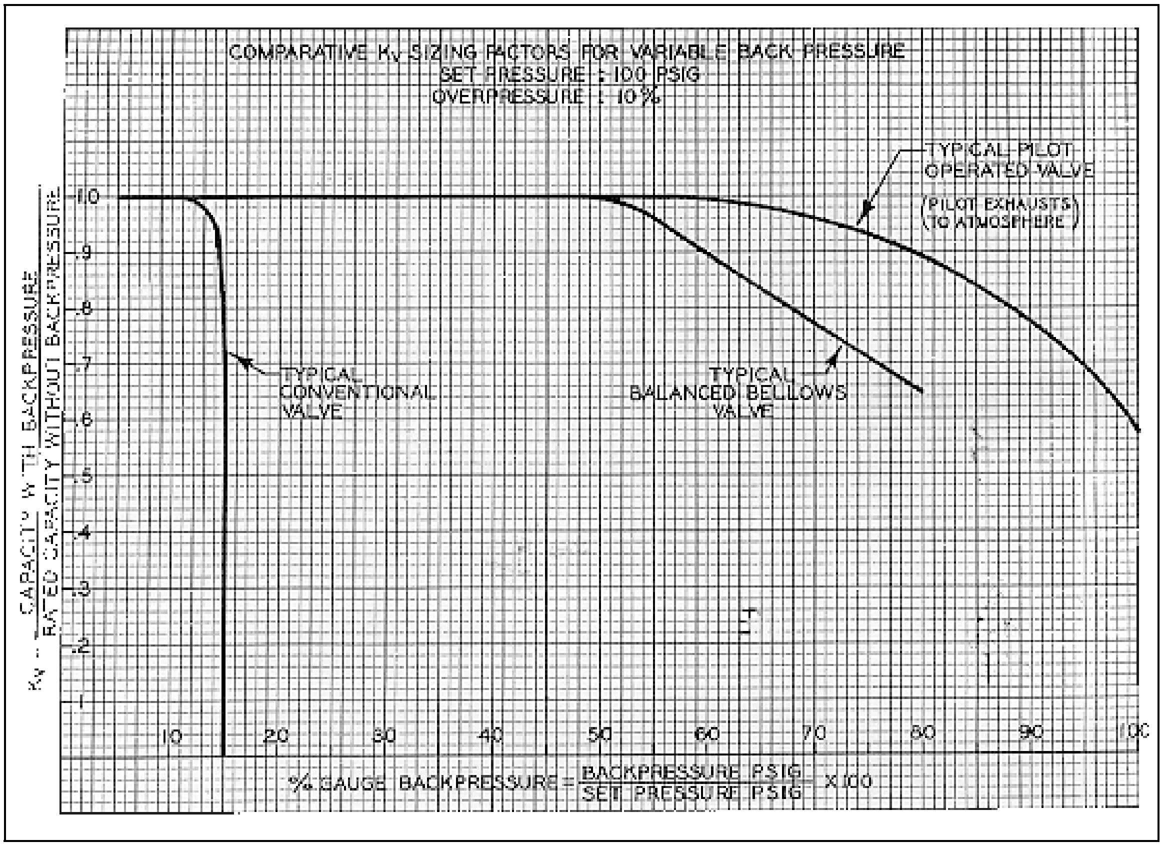
To cost-effectively analyze the flare system hydraulics a network model of the flare collection system must be constructed in a suitable flare modeling program. This involves characterizing the geometric layout of the flare main header, sub-headers, and relief device piping, including appropriate dimensional aspects.

Backpressure is an important aspect to consider when conducting a flare systems analysis. Backpressure is the pressure that exists at the outlet of a pressure relief device as a
result of the pressure in the discharge system. Back pressure can be either constant or variable depending on the nature of the equipment relieving into the system. Back pressure is the sum of the superimposed (constant) and built-up back pressure.

A backpressure curve is first calculated for each individual relief device, including the inlet line, relief device, and discharge line.
This backpressure curve provides a graph of flowrate versus surrounding backpressure, and typically varies depending on relief device type (conventional, bellows, or pilot). Figure 1 provides an example of typical backpressure curves for different valve types.

Once the individual devices have been modeled, each one is connected into a header within the model in the same configuration as in the field. Finally the relief loads for the particular global scenario being evaluated are applied to each of the relief devices in the model.

Figure 1- Backpressure Curves for Conventional Bellows, and Pilot Valves



Source: GPSA Engineering Handbook 9th Edition

2.4 ANALYZE FLARE SYSTEMS HYDRAULICS

For each global overpressure scenario, the flare network model is executed by combining the flows from individual relief devices, to obtain a base-case flare system profile. This calculation establishes:

- Backpressure, flow reduction, pressure accumulation (%MAWP), and temperature accumulation (%MAWT) for protected equipment
- Sub-header, main header, and flare tip flow restrictions
- Reaction forces and vibration risk
- Exclusion zones for thermal radiation and noise restrictions
- Dispersion estimates in case of flame out

2.5 FLARE SYSTEM DESIGN CHECKS

Having completed one flare system hydraulic calculation, it is necessary to ensure that the flare system and all its components are performing satisfactorily within defined limits.

Typical flare system design and operating constraints are shown in Tables 1 and 2. These design and operating constraints can differ depending on where the facility is located and who the operator/owner is.

Table 1: Typical Flare System Hydraulics Design and Operating Constraints

Design Criteria	Value	Description
Maximum Flow Velocity	Mach ≤ 0.6	Maximum value for header and sub-headers design
Flow rate	Rated Capacity	Value for sub-headers and relief discharge piping design
	Required Capacity	Value for main header design
Backpressure	≤ 0.1 P_{set}	Conventional relief valves
	≤ 0.3 P_{set}	Balanced relief valves. Balanced relief valves may be accepted for backpressures up to 0.5 P_{set} with prior consultation with manufacturer and design consultant
	≤ 0.5 P_{set}	Pilot operated valves. Pilot relief valves will be accepted for backpressures up to 0.7 P_{set} with prior consultation with manufacturer and design consultant

Table 2: Typical Flare System Thermal Radiation and Noise Design and Operating Constraints

Design Criteria	Value		Description
Radiation Intensity Solar radiation component should be added and can be as high as 1 kW/m^2 in some locations.	1.57 kW/m^2	500 $BTU/h\ ft^2$	Value at any location where personnel with appropriate clothing may be continuously exposed
	1.98 kW/m^2	630 $BTU/h\ ft^2$	Maximum value for pressurized storage equipment
	3.15 kW/m^2	1000 $BTU/h\ ft^2$	Maximum value for atmospheric storage equipment
	4.72 kW/m^2	1500 $BTU/h\ ft^2$	Heat intensity in areas where emergency actions lasting several minutes may be required by personnel without shielding but with appropriate clothing. Maximum value for Process equipment.
	6.30 kW/m^2	2000 $BTU/h\ ft^2$	Heat intensity in areas where emergency actions up to 1 minute may be required by personnel without shielding but with appropriate clothing. Maximum value for Knock Out Drum.
	9.45 kW/m^2	3000 $BTU/h\ ft^2$	Heat intensity at any location to which people have access; exposure should be limited to a few seconds, sufficient for escape only.
Emergency Flaring Noise (working areas)	85 dBA		At maximum flaring load
Emergency Flaring Noise (residential areas)	80 dBA		At maximum flaring load
Normal operation Flaring Noise (residential areas)	68 dBA		At maximum flaring load

A summary of the flare system design checks to consider are as follows:

Flow Capacity: When reviewing the flare system hydraulics output, the overall hydraulics report will provide flow characteristics for the main header, sub-headers and relief piping. This allows required flowrate to be compared with total calculated flowrate; thereby determining if adequate flow capacity is provided.

Individual Relief Device Performance: The base-case profile is also used to identify any individual relief devices that are deficient – a relief device that may appear adequately sized for an individual calculation can be deficient during a global overpressure scenario due to a higher backpressure in the system.

For conventional relief valves, backpressures exceeding 10% typically result in no flow. For pilot-operated relief valves, backpressures greater than the choked flow pressure ratio (typically 55% - 65%) will cause subsonic flow and flow reduction. For bellows type relief devices, backpressures exceeding 30% will typically result in flow reduction, depending on the allowable overpressure and valve model.

Many deficiencies are often associated with relief device instability caused by excessive inlet pressure loss or backpressure. Shelly (1999), confirms our experience that 30 to 40 % of pressure relief valves in existence violate recommended guidelines for inlet pressure loss and backpressure. Excessive pressure loss can lead to valve instability and possibly valve failure. As a result, many operating companies are faced with significant upgrade or mitigation costs.

Non-flowing relief systems: Non-flowing relief devices and rupture disks also require consideration. Pressure relief devices are designed to withstand a maximum amount of backpressure when it is not flowing. The API Standard 526 for flanged pressure relief devices are typically used as the screening criterion for superimposed backpressures. Individual manufacturers also publish tested limits. For rupture disks, if the superimposed backpressure in a header approaches the bursting pressure of a disk that is not relieving, the disk may burst allowing flow into the equipment it is designed to protect. As a result, any superimposed backpressures that are greater than 75% of the burst pressure of the rupture disk should be identified for attention.

For bellows relief devices, superimposed backpressure may lower the opening pressure of the relief valve, and thereby cause the relief valve to open. In some cases, where the header pressure exceeds the set pressure of a bellows type relief valve, the valve may open and allow header fluid to flow into the protected equipment. As a result, any superimposed backpressures that are greater than 75% of the set pressure of the bellows-type relief valve should be identified for attention.

Flare header velocity: Flare header velocity should be considered. Acceptable velocities within the collection system are typically 60% - 70% of the Mach number. However, for low velocity (subsonic) flares, a flare tip velocity of 50% of the Mach number is recommended by API.

Temperatures: Header and piping temperatures should be evaluated to determine if the temperature in the collection system or effluent handling equipment is lower than the minimum design metal temperature (MDMT), or exceeds the design temperature. Temperatures outside of these limits may challenge the mechanical integrity of the piping or vessels.

Consequence Effects: Thermal radiation, noise, and dispersion estimates should be considered. Dispersion should consider concentrations from both flammability limits and any toxic impact, in the event of a flame out.

Piping Surface Roughness: The use of piping surface roughness should be carefully considered when conducting a flare systems analysis. Typical surface roughnesses are given in Table 3 for new piping. However, as Figures 2 and 3 show, the surface roughness and actual flow area of existing piping may differ greatly from original design calculations. For existing piping, the surface roughness may be up to ten times that of the new pipe value.

Reaction Forces: Header and sub-header piping should always be checked for reaction forces and vibration risk, especially in depressuring systems. As shown in Figure 4, inadequately supported piping can fail catastrophically.

Separation Vessels: Knock-out drums need to be considered for size, operating and design pressure, retention time, and path length or superficial vapor velocity required to achieve separation.

Table 3 – Typical Pipe Roughness

Type	Roughness (m)	Roughness (in)	Roughness (ft)
Cast Iron	0.000260	0.0102362	0.000853018
Wrought Iron	0.0000457	0.0017992	0.000149934
Commercial Steel	0.0000457	0.0017992	0.000149934
Galvanized Iron	0.000152	0.0059843	0.000498688
Asphalted Cast Iron	0.000122	0.0048032	0.000400262
Drawn Tubing	0.0000152	0.00059843	0.0000498688

Figure 2 – Pipe Roughness Example – Accumulation of Fouling

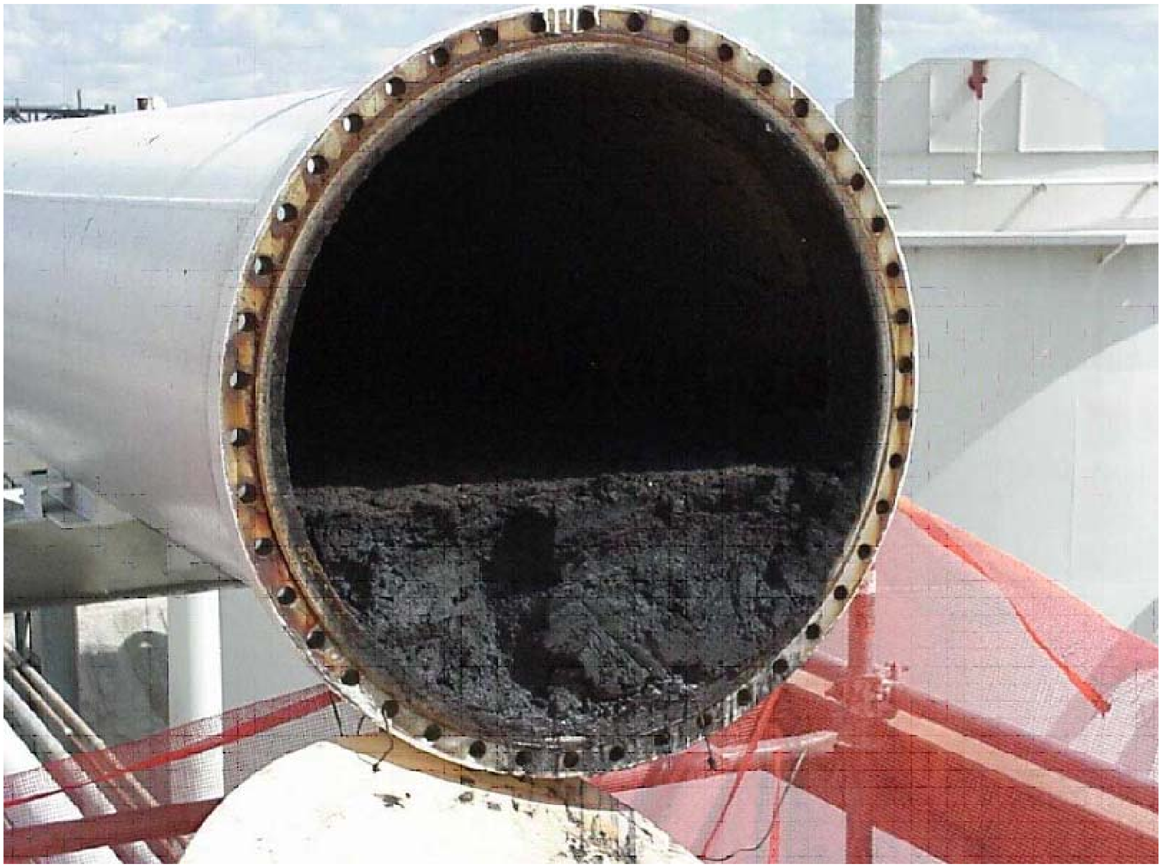


Figure 3 – Pipe Roughness Example – Accumulation of Fouling

Figure 4 – Reaction Force Example – Failure of Unsupported Piping

2.6 Resolve Design Deficiencies

At this point, an evaluation of options to correct the deficiencies is undertaken, with the purpose of maximizing the use of the existing flare collection system. Options that are usually considered include:

- Automate shutdowns and/or isolation systems currently requiring operator intervention
- Maximum use of bellows/pilot relief valves
- Account for actual timing of loads (e.g., automated de-pressuring systems)
- Make reasonable header and relief piping size adjustments to correct deficiencies, if possible
- Model vessel dynamics and establish actual pressure and temperature accumulation based on flare pressure profiles when using (a) reduced set points less than MAWP, and where (b) the required flow rate is less than the actual relief device rated capacity.

If all these aspects have been thoroughly investigated and evaluated, consideration of High Integrity Protection Systems (HIPS) is an alternative option. HIPS are typically comprised of instrumentation, final control elements (valves, switches), and logic solvers, which are designed to avoid overpressure incidents by either removing the source of overpressure, or by reducing the probability of an overpressure contingency to a negligible level.

2.7 RE-ANALYZE FLARE SYSTEMS HYDRAULICS

After having addressed any design deficiencies, the flare system hydraulic analysis is performed again, and design checks are conducted. This is an iterative process until no more deficiencies are identified.

Flare systems mitigation can be costly. Careful analysis and use of accurate and detailed simulation tools will ensure continued safety and a cost effective mitigation implementation where required. SuperChems™ Expert, or other flare network modeling software, can be used to produce more accurate answers for flow dynamics and flare sub-header optimization. This is crucial for effective selection of mitigation options where necessary.

3. CASE STUDY

ioMosaic recently undertook a flare systems analysis for a large oil refinery with a very complex flare network that had been modified numerous times over the lifetime of the facility. It had six separate flares, three main headers, and hundreds of relief devices that discharged into the system. As the flare system was modified over the years, multiple cross-connection points were added between the headers in an effort to balance the flow rates through the headers with minimal piping changes.

3.1 THE CHALLENGE

The problem was that the system had become so complex that the tools the refinery was using to evaluate the flows through the flare network could not adequately model the system. Management no longer had confidence that the model results reflected the actual network performance and therefore, could not be sure the system would perform properly in the event of a global relief scenario at the facility.

3.2 APPROACH

ioMosaic developed an accurate model of the flare network and evaluated the performance during a total refinery power failure scenario.

To do this, ioMosaic constructed a model of the flare network in their software package, SuperChems. The backbone of the model included developing piping isometrics for all of the relief devices, headers and flares involved in a total refinery power outage based on the actual field piping isometrics provided by the client. All of the relief devices associated with this scenario were also modeled using the valve details provided by the client.

Once the physical details of the flare network had been entered into the program, the network was divided into sections to assist with the complex calculations. Points where the flows could cross between headers were identified as Nodes. Some of these Nodes had relief devices providing flow into the Node and others were only potential cross-over points between the different headers, but no new flow was added. For each Node where relief devices provide flow into the Node, the relief devices were grouped together. The network ended up with 11 groups of relief devices and 20 network Nodes as shown in Figure 1. The Groups of relief devices ranged from just 1 relief device up to 19 devices in each group.

A back-pressure curve was generated for each relief device using the specific characteristics of the relief valve and the chemical components flowing through it. Next a back-pressure curve was generated for each Group of relief devices. This provided an initial look at how the relief devices would perform when multiple devices were flowing simultaneously.

All of the network Nodes were then defined with interconnecting piping isometrics and information about where flow could come from and go to for each node. In many instances, flow could go either direction through a cross-over pipe connecting two headers depending on what the pressure was at each of the connecting Nodes. The other software packages ran into trouble without a defined flow path through each of these connection points. However, it wasn't possible to confirm the flow direction until the pressures were identified.

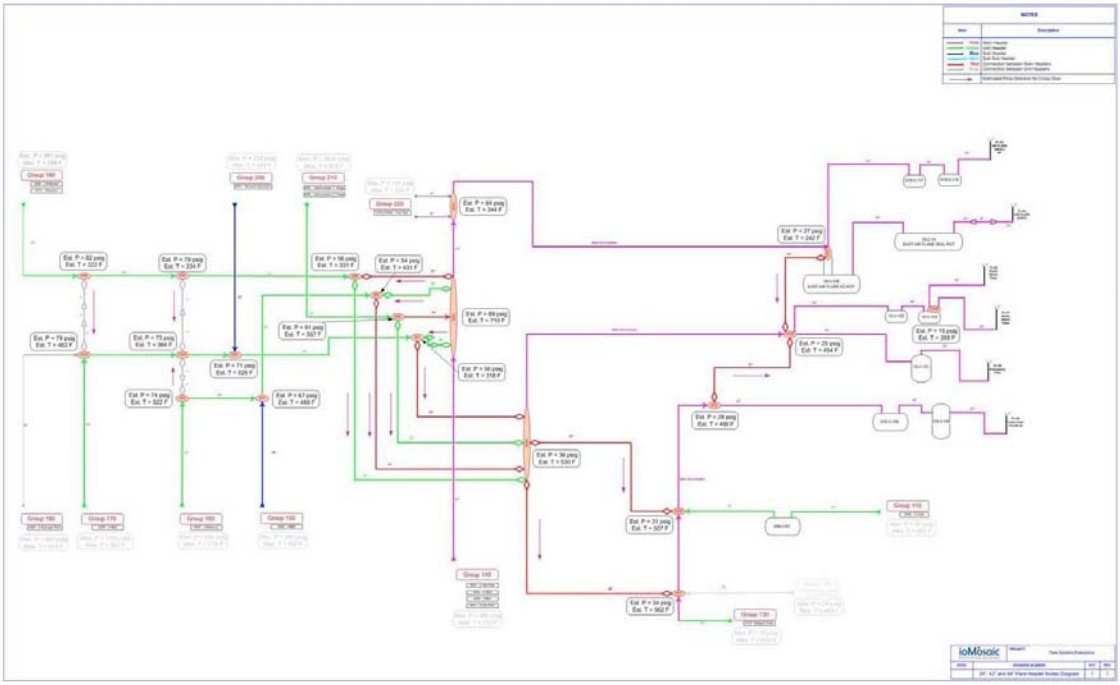
Once all of the Nodes were defined, the software generated the equivalent of back-pressure curves at multiple temperatures and pressures for each Node, called Flow Maps (as shown in Figure 5). These Flow Maps were used to converge the network solution. The software provided temperatures and pressures for each Node and the flows through the network, including which direction the flow was going through each of the network cross-over connections.

The final step in the analysis was to review each of the groups of relief devices and determine how much flow could pass through each device with the back-pressure at the first network Node as determined above. These relief device flow rates could then be compared to the required flow rates for this particular relief scenario to determine if the relief device and network piping could meet the demand.

Once the model was developed, modifications to the network could be easily examined. If safeguards are present which eliminate the relief load from a particular device, that device can be disabled by a single click. Changes to the type of relief device (conventional, bellows or pilot) can be easily examined. The hydraulic analysis output identifies the pressure drops through each segment of piping allowing the user to quickly determine which sections of piping should be modified to achieve the greatest performance improvement within the network.

Based on the changes that are made, it is possible to re-evaluate the flows through the network. In some cases, if flows are removed from certain groups, then the pressure drops and flow might reverse direction through one of the cross-over connections. SuperChems can identify these changes in flow direction and provide a new solution to the flow network.

Figure 5 – Flare System Analysis Node Map



3.3 CONCLUSION

This flare systems analysis provided some good insight to the dynamics of the flare system. It was able to highlight some valves which were undersized, regardless of the piping configuration and flows throughout the network. It identified several relief valves which would not provide any flow because the back-pressures in that section of the flare network would be higher than the inlet pressure for the relief device.

The model was used to evaluate the effectiveness of various safeguards to reduce the flow rates during this total refinery power failure scenario. The model was also useful in identifying some valves which would benefit from changing from a balanced-bellows style to a pilot device. It also pointed out some bottlenecks in the piping system, which needed to be modified to allow proper flows through all of the relief devices upstream.

In summary, ioMosaic was able to produce a dynamic model of a very complex flare network where all other software packages came up short. Once developed, the model is easily modified to stay current with changes to the system.

4. REFERENCES

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