

Gas in shell, propane in tube, the STHE represents the evaporator of a propane chiller

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Item** | **Study Node** | **Process Parameter** | **Guideword (Deviation)** | **Possible Causes** | **Possible Consequences** | **Action Required** |
| 1A | *Cool Gas* | Flow | No | 1. Gas supply failure | No gas, downstream processes upset | Install flow meter and low flow alarm |
|  |  |  |  | 1. Valve closure | Same as above | Same as above, add valve lock |
|  |  |  |  | 1. Line plugging | Same as above | Same as 1A.1, regular maintenance |
|  |  |  |  | 1. Line rupture | Same as above, gas leakage, flammable mixture formation risk | Same as above, install automatic shutdown system, bypass line, adequate ventilation and fire protection system |
| 1B |  |  | More | 1. Increased supply pressure | High gas flow, downstream process upset | Install flow meter, high flow alarm, relief valve and ventilation, pressure sensor and high-pressure alarm |
| 1C |  |  | Less | 1. Partial gas supply failure | Low gas flow, downstream process upset | Same as 1A.1 |
|  |  |  |  | 1. Low supply pressure | Same as above | Same as 1A.1, install pressure sensor and low-pressure alarm |
|  |  |  |  | 1. Partial valve closure | Same as above | Same as 1A.2 |
|  |  |  |  | 1. Partial line plugging | Same as above | Same as 1A.3 |
|  |  |  |  | 1. Line rupture | Same as above, gas leakage, flammable mixture formation risk | Same as 1A.4 |
| 1D/E/F |  |  | As well as/Part of/Other than | 1. Supply contamination | Contamination, downstream process upset | Quality control |
| 1G |  |  | Reverse | 1. High downstream pressure | Backflow into supply | Install check valve, pressure sensor, high-pressure alarm, relief valve and ventilation, check downstream process |
| 1H/I |  |  | Early/Late | 1. Early/late valve opening | Downstream process upset | Check downstream process |
| 1J/K |  | Temperature | High/Low | 1. Temperature control failure | Line and shell damage under stress, gas leakage and combustion, downstream process upset | Install temperature sensor, alarm, redundant control system and power backup, fire protection system regular maintenance |
| 1L |  | Pressure | Low | 1. Control valve failure | Reduced cooling, downstream process upset | Regular maintenance, install pressure sensor and alarm |
|  |  |  |  | 1. Pump failure | Same as above | Same as above, install backup pump and power |
|  |  |  |  | 1. Blockages | Same as above | Same as 1L.1 |
|  |  |  |  | 1. Line rupture | Same as 1C.5 | Same as in 1A4 |
| 1M |  |  | High | 1. Control valve failure | Line and shell damage under stress, gas leakage and combustion, downstream process upset | Same as 1L.1, install relief valve, fire protection system and ventilation |
|  |  |  |  | 1. Outlet blockage | Same as above | Same as above |
| 2A | *Propane In* | Flow | No | 1. Compressor failure | No propane, no cooling of gas, downstream processes upset | Install flow meter and low flow alarm, regular maintenance, install backup compressor and power |
|  |  |  |  | 1. Valve closure | Same as above | Install flow meter and low flow alarm, add valve lock |
|  |  |  |  | 1. Line plugging | Same as above | Install flow meter and low flow alarm, regular maintenance |
|  |  |  |  | 1. Line rupture | Same as above, propane leakage, flammable mixture formation risk | Same as above, install automatic shutdown system, bypass line, fire protection system and adequate ventilation |
| 2B |  |  | More | 1. Increased supply pressure | High propane flow, unnecessary extra gas cooling, propane and compressor power wastage, downstream process upset | Install flow meter, high flow alarm, relief valve and ventilation, pressure sensor and high-pressure alarm |
| 2C |  |  | Less | 1. Compressor malfunction | Low propane flow, reduced gas cooling, downstream process upset | Same as 2A.1 |
|  |  |  |  | 1. Low supply pressure | Same as above | Install flow meter and low flow alarm, pressure sensor and low-pressure alarm |
|  |  |  |  | 1. Partial valve closure | Same as above | Same as 2A.2 |
|  |  |  |  | 1. Partial line plugging | Same as above | Same as 2A.3 |
|  |  |  |  | 1. Line rupture | Same as above, propane leakage, flammable mixture formation risk | Same as 2A.4 |
| 2D/E/F |  |  | As well as/Part of/Other than | 1. Supply contamination | Contamination, cooling upset, downstream process upset | Quality control |
| 2G |  |  | Reverse | 1. High downstream pressure | Backflow into supply | Install check valve, pressure sensor, high-pressure alarm, relief valve and ventilation, check downstream process |
| 2H/I |  |  | Early/Late | 1. Early/late valve opening | Wasteful chiller operation, downstream process upset | Check downstream process |
| 2J/K |  | Temperature | High/Low | 1. Temperature control failure | Line and tube damage under stress, propane leakage and combustion, reduced/excess gas cooling, downstream process upset | Install temperature sensor, alarm, redundant control system and power backup, fire protection system, regular maintenance |
| 2L |  | Pressure | Low | 1. Control valve failure | Reduced gas cooling, downstream process upset | Regular maintenance, install pressure sensor and alarm |
|  |  |  |  | 1. Compressor failure | Same as above | Same as above, install backup compressor and power |
|  |  |  |  | 1. Blockages | Same as above | Same as 1A.1 |
|  |  |  |  | 1. Line rupture | Same as 2C.5 |  |
| 2M |  |  | High | 1. Control valve failure | Line and tube damage under stress, propane leakage and combustion, downstream process upset | Same as 2L.1, install relief valve, fire protection system and ventilation |
|  |  |  |  | 1. Outlet blockage | Same as above | Same as above |
| 3A | *Cold Gas* | Flow | No | 1. Same as 1A |  |  |
|  |  |  |  | 1. Shell damage in exchanger | No gas, downstream process upset, gas leakage, flammable mixture formation risk | Install flow meter, low flow alarm, automatic shutdown system, adequate ventilation, low flow alarm in exchanger, fire protection system |
| 3B |  |  | More | 1. Same as 1B |  |  |
| 3C |  |  | Less | 1. Same as 1C |  |  |
|  |  |  |  | 1. Shell damage in exchanger | Same as 3A.2 |  |
| 3D/E/F |  |  | As well as/Part of/Other than | 1. Supply contamination | Contamination, downstream process upset | Quality control |
|  |  |  |  | 1. Tube damage in exchanger | Propane leakage causes contamination, downstream process upset | Regular maintenance, install high flow alarm in exchanger and line |
| 3G |  |  | Reverse | 1. Same as 1G |  |  |
| 3H/I |  |  | Early/Late | 1. Same as 1H/I |  |  |
| 3J/K |  | Temperature | High/Low | 1. Same as 1 J/K |  |  |
|  |  |  |  | 1. Inadequate propane flow and specifications | Same as 2 |  |
|  |  |  |  | 1. Interaction with external environment | Same as 1J/K | Install and maintain insulation |
| 3L |  | Pressure | Low | 1. Same as 1L |  |  |
| 3M |  |  | High | 1. Same as 1M |  |  |
| 4A | *Propane Out* | Flow | No | 1. Same as 2A |  |  |
|  |  |  |  | 1. Tube damage in exchanger | No propane, downstream process upset, propane leakage and mixing with gas, flammable mixture formation risk | Install flow meter, low flow alarm, automatic shutdown system, adequate ventilation, high flow alarm in exchanger, fire protection system |
| 4B |  |  | More | 1. Same as 2B |  |  |
| 4C |  |  | Less | 1. Same as 2C |  |  |
|  |  |  |  | 1. Tube damage in exchanger | Same as 4A.2 |  |
| 4D/E/F |  |  | As well as/Part of/Other than | 1. Supply contamination | Contamination, downstream process upset | Quality control |
|  |  |  |  | 1. Tube damage in exchanger | Propane leakage causes contamination, downstream process upset | Regular maintenance, install high flow alarm in exchanger and line |
| 4G |  |  | Reverse | 1. Same as 2G |  |  |
| 4H/I |  |  | Early/Late | 1. Same as 2H/I |  |  |
| 4J/K |  | Temperature | High/Low | 1. Same as 2 J/K |  |  |
|  |  |  |  | 1. Inadequate gas flow and specifications | Same as 1 |  |
|  |  |  |  | 1. Interaction with external environment | Same as 2J/K | Install and maintain insulation |
| 4L |  | Pressure | Low | 1. Same as 2L |  |  |
| 4M |  |  | High | 1. Same as 2M |  |  |
| 5A/B | *Heat Exchanger* | Temperature | Low/High | 1. Same as 1/2/3/4J/K |  |  |
| 5C/D |  | Pressure | Low/High | 1. Same as 1/2/3/4L/M |  |  |
| 5E/F |  | Normal Functioning | Fouling/Corrosion | 1. Supply contamination | Leakage, reduced heat transfer, downstream process upset | Regular maintenance, supply quality control |
|  |  |  |  | 1. Chemical deposition | Same as above | Same as above |
| 5G |  |  | Damage | 1. Same as 1/2/3/4J/K/M |  |  |
| 6A | *Control Systems* | Normal Functioning | Failure | 1. Faulty sensors | Incorrect readings, upsets in heat transfer and downstream processes, damage to equipment | Regular maintenance, install redundant control systems |
|  |  |  |  | 1. Circuital problems | Same as above | Same as above |
|  |  |  |  | 1. Power loss | Same as above | Same as above, install backup power |