TEAM 012

VR-INTEGRATED FLARE SYSTEM DESIGN FOR SAFE MANAGEMENT IN SOUR GAS RECOVERY UNITS

Jumanah Rifadah, Afnan Alqubaysi, Njood Aldughaimi, Remaz Altamimi- Sadeem Alotaibi- Renad Alqahtani
Coach: Dr. Hani Al-Mohair

CHE ICS 3 ISE

Background

- Sour gas streams contain toxic H_2S, posing serious safety risks
- Flare systems are required for safe gas disposal during abnormal conditions
- Lack of integration between systems leads to inefficient gas handling
- Limited visualization reduces operator understanding of system behavior

Novelty

A unified, real-time digital twin that couples VR immersion with predictive process simulation to proactively guide operator decisions before hazardous flare events escalate.

Objectives

- Develop a VR-integrated flare management system for safer training and operation.
- Present Aspen HYSYS results and simulate abnormal scenarios
- Enhance learning to flare system and response actions through visualization.

Constraints

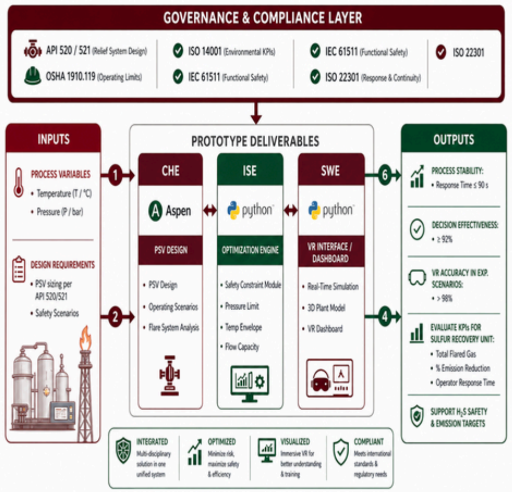
- PSV — Max relieving pressure ≤ 110% set pressure (non-fire) | 121% (fire)
- VR camera motion limited — No flashing > 3 Hz for user comfort
- Operator response time ≤ 120 sec alarm

Prototype Development

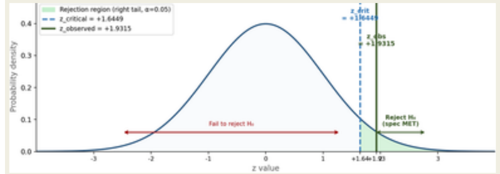
Specifications

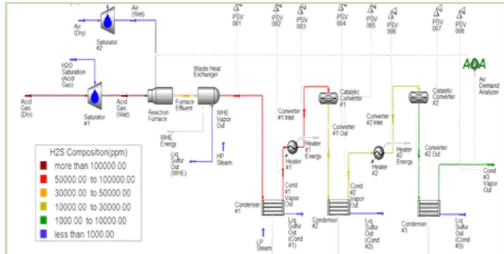
- Removes liquid droplets diameter ≥ 300 μm
- Flare stack ≥ 98% combustion efficiency, stable
- Thermal radiation limited to ≤ 6.3 kW/m²
- Flared gas emissions reduced by ≥ 5% vs baseline
- System latency ≤ 20 ms
- Optimization validated at 95% confidence level
- VR data visualization accuracy ≥ 98%
- User decision effectiveness ≥ 92%
- VR system operates at ≥ 72 FPS
- System evaluates ≥ 3 KPIs for SRU–flare routing decision

System Design



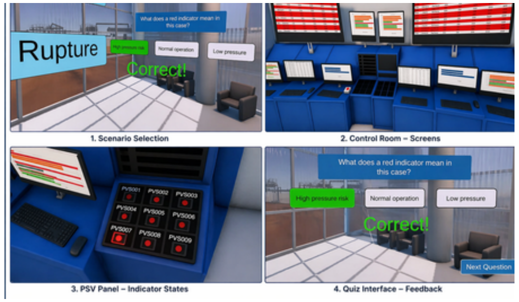
Validation & Verification





Decision Eff.	VR Accuracy	KPI Eval.
96.43%	99.77%	3 KPIs
≥92% · p=0.027	≥98%	RT · Util · Margin

Results & Conclusion



An integrated SRU–flare system with optimization and VR visualization was developed to enhance safety, reduce emissions, and improve decision-making. The multidisciplinary approach ensures efficient gas routing, reliable operation, and compliance with performance targets.

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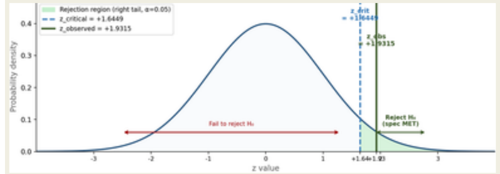

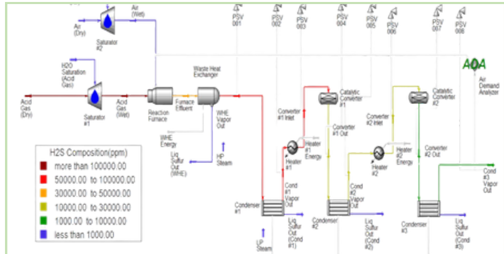

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Objectives

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Constraints

- Max relieving pressure $\leq$ 110% set pressure (non-fire) | 121% (fire)
- VR camera motion limited No flashing > 3 Hz for user comfort
- Operator response time $\leq$ 120 sec alarm

Specifications

- Removes liquid droplets diameter $\geq$ 300 μm
- Flare stack $\geq$ 98% combustion efficiency, stable
- Thermal radiation limited to $\leq$ 6.3 kW/m²
- Flared gas emissions reduced by $\geq$ 5% vs baseline
- System latency $\leq$ 20 ms
- Optimization validated at 95% confidence level
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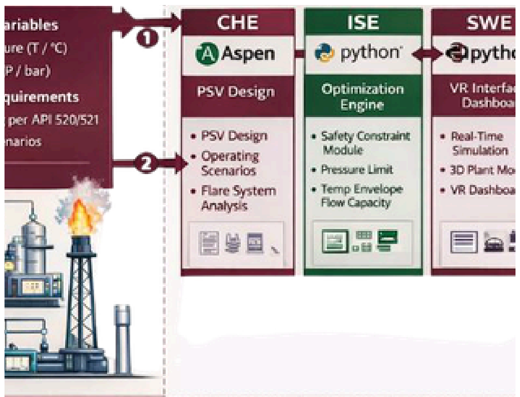

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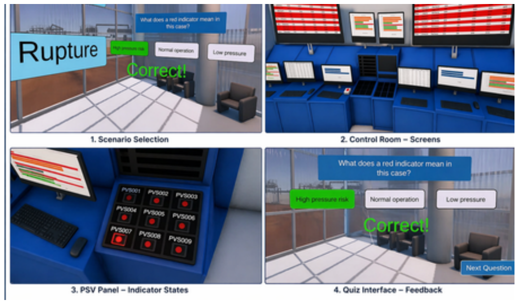

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Prototype Development

Specifications

- Removes liquid droplets diameter ≥ 300 µm
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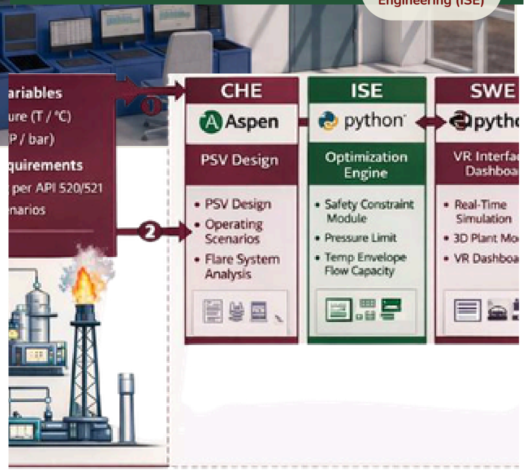

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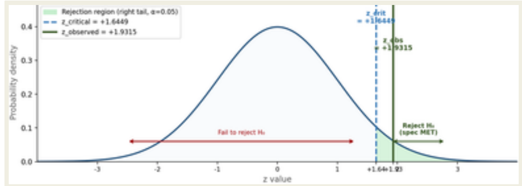
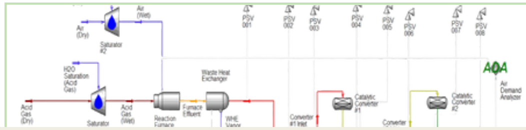
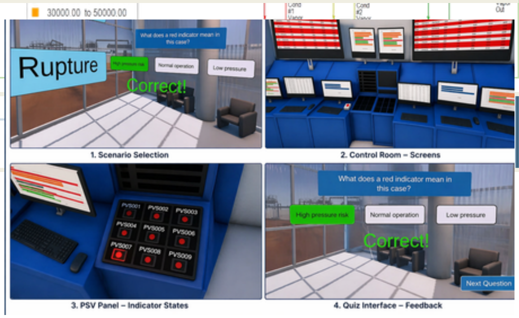




Results & Conclusion



An integrated SRU–flare system with optimization and VR visualization was developed to enhance safety, reduce emissions, and improve decision-making. The multidisciplinary approach ensures efficient gas routing, reliable operation, and compliance with performance targets

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CHE
ICS 3 ISE

Objectives

- Develop a VR-integrated flare management system for safer training and operation.
- Present Aspen HYSYS results and simulate abnormal scenarios (e.g., blocked outlet, rupture) in an interactive environment
- Support faster and better operator decision during emergency and upset condutions.
- Enhance learning to flare system and response actions through real time visualization.

Background & Problem Statement

- Sour gas streams contain toxic H_2S, posing serious safety risks
- Flare systems are required for safe gas disposal during abnormal conditions
- Lack of integration between systems leads to inefficient gas handling
- Limited visualization reduces operator understanding of system behavior
- This results in poor decision-making and increased safety risks during emergencies

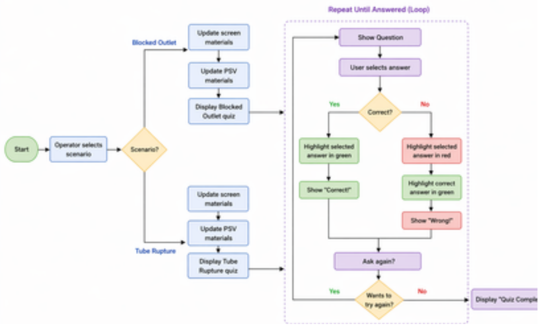
Constrains

- PSVs are sized such that the maximum relieving pressure does not exceed 110% of the set pressure for non-fire contingencies and 121%
- Operator Response Time Alarm sec.
- VR scenes are designed for user comfort by limiting camera motion and avoiding high- contrast flashing above 3 Hz.

Specifications

- The KOD removes liquid droplets with diameter ≥ 300 microns
- Thermal radiation is limited to ≤ 6.3 kW/m^2
- Flare stack achieves ≥ 98% combustion efficiency with stable operation
- Optimization results are validated at 95% confidence level
- Flared gas emissions are reduced by ≥ 5% compared to baseline
- VR system operates at ≥ 72 FPS
- System latency ≤ 20 ms
- User decision effectiveness ≥ 92%
- VR data visualization accuracy ≥ 98%
- The system evaluates ≥ 3 KPIs for SRU–flare routing decisions

System Design

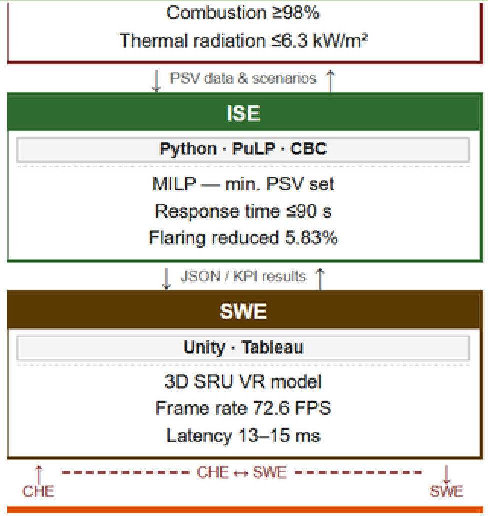


Prototype Development

Validation & Verification

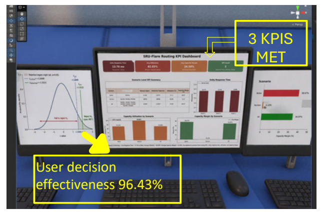
- Constraints fully validated, including PSV relieving pressure limits, response time, and VR motion.
- Specifications met, including combustion efficiency ≥98%, thermal radiation ≤6.3 kW/m^2, liquid removal ≥90%, emissions reduced to 5.74% with 95% CI validated, VR 72.6 FPS, and latency 13–15 ms.

System Architecture



Results & Conclusion

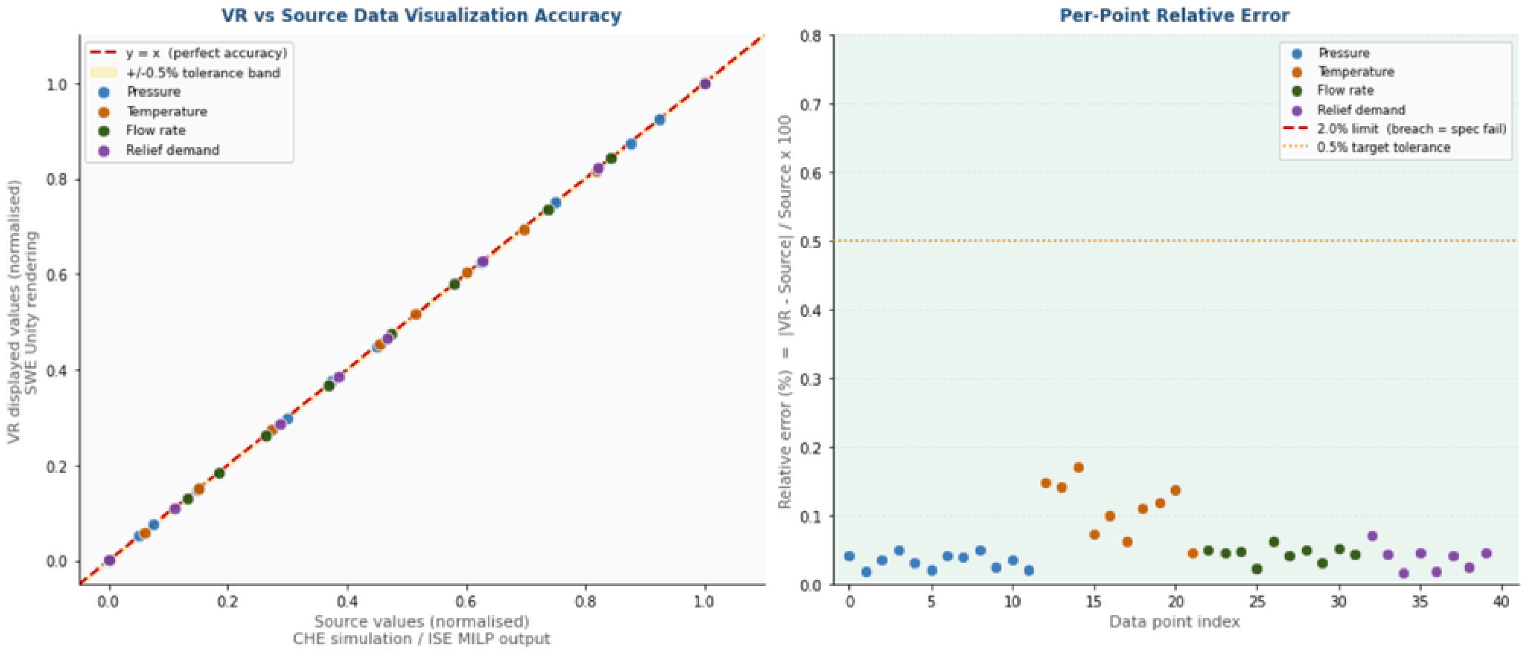
- User decision effectiveness 96.43%, VR accuracy 99.77%, and 3 KPIs (VR response time 13.78 ms, utilization 82.03%, and capacity 24.59%)



INTEGRATED SPEC #2

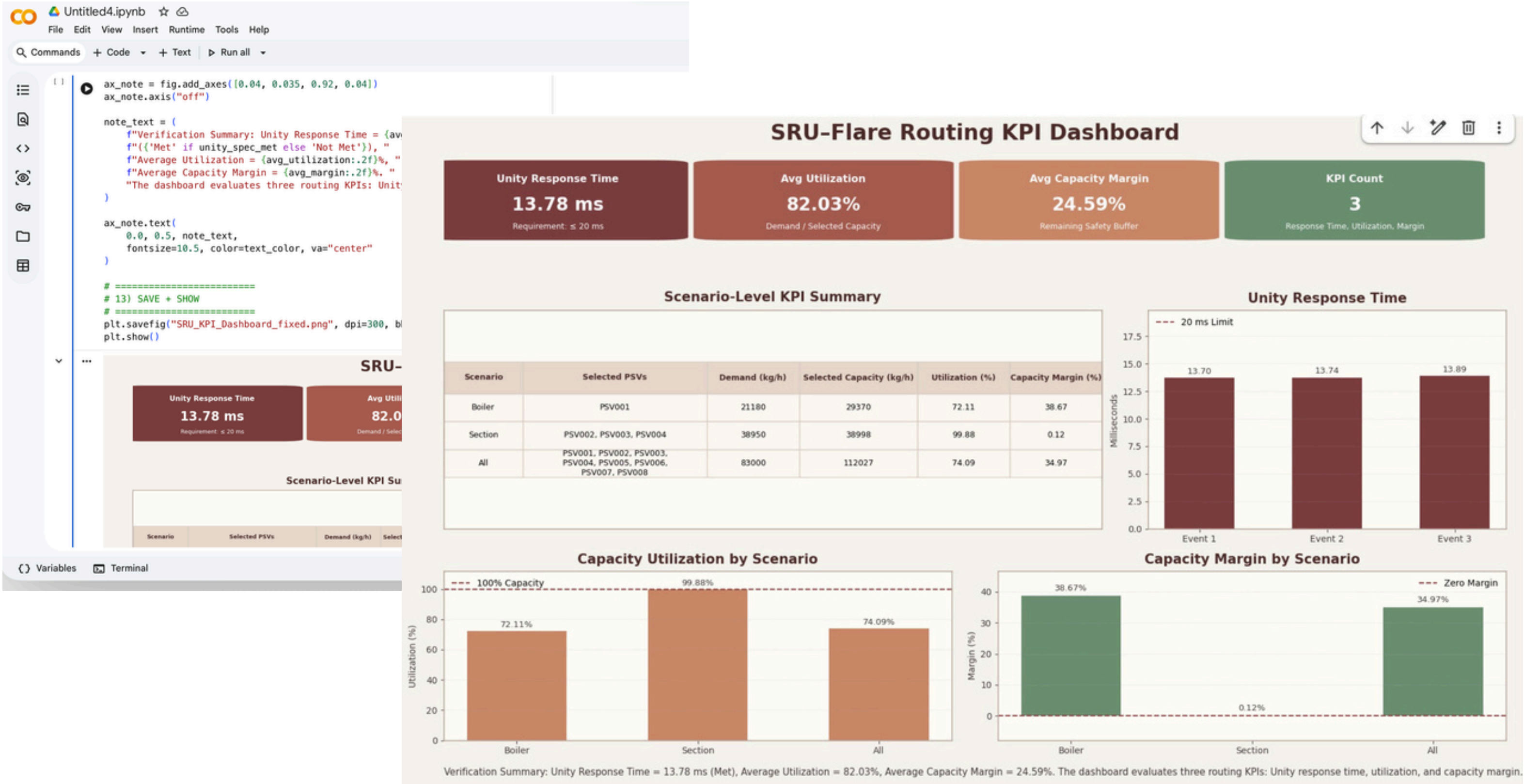
```
all_below = bool(rel_err.max() < 2.0)
plt.tight_layout()
plt.savefig("vr_accuracy_scatter.png", dpi=180,
            bbox_inches="tight", facecolor="white")
plt.show()
print("Plot saved as: vr_accuracy_scatter.png")
```

```
==============================================
   VR ACCURACY SUMMARY
==============================================
  Total data points    : 40
  Mean accuracy        : 99.943%
  Max relative error   : 0.171%
  Within +/-0.5%       : 100.0% of points
  Within +/-1.0%       : 100.0% of points
  Specification (>=98%): PASS
==============================================
```



Data visualization accuracy for VR ≥ 98 %	**Met**

INTEGRATED SPEC #3



What the Dashboard Shows

Evaluates routing performance using 3 main KPIs:

- Unity Response Time (software performance)
- Capacity Utilization (efficiency)
- Capacity Margin (safety buffer)

Covers 3 scenarios: Boiler, Section, All

KPI Equations

1. Unity Response Time

$$\overline{RT} = \frac{1}{n}\sum RT_i$$

- Measures system responsiveness (VR/software)
- Independent from process scenarios

2. Selected Capacity

$$C_s = \sum Q_i$$

- Total capacity of selected PSVs
- Depends on routing decision

3.Utilization

$$U_s = \frac{D_s}{C_s} \times 100$$

- Measures how much capacity is used
- Close to 100% → near limit

4. Capacity Margin

$$M_s = \frac{C_s - D_s}{D_s} \times 100$$

- Measures remaining safety buffer
- Higher = safer

INTEGRATED SPEC #1

p-value Calculation

$$\text{p-value} = P(Z > 1.9315) = 1 - \Phi(1.9315) = 0.0267$$

Confidence Interval

The 95% confidence interval for the true proportion is:

$$CI = \hat{p} \pm 1.96\sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$$
$$= 0.9643 \pm 1.96 \times 0.01566 = (0.9336, 0.9950)$$

Final Decision

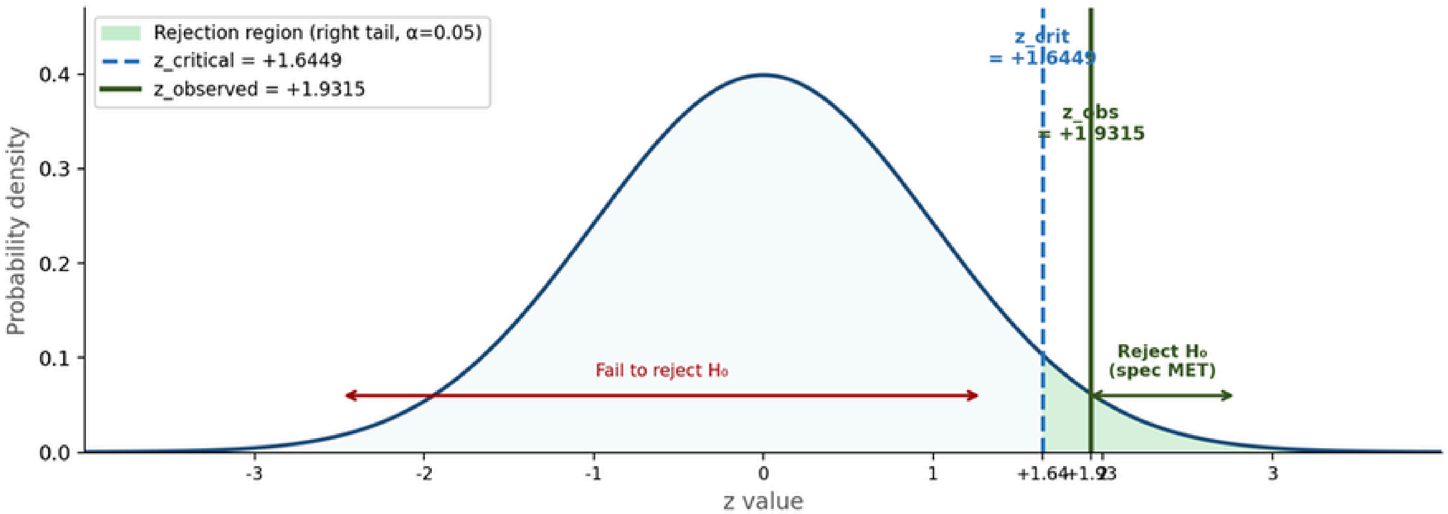
Since:

$$z = 1.9315 > 1.6449 \text{and} \text{p-value} = 0.0267 < 0.05$$

We reject the null hypothesis H_0.

There is sufficient statistical evidence to conclude that the user decision effectiveness exceeds 92%.
Therefore, the system successfully satisfies the required specification:

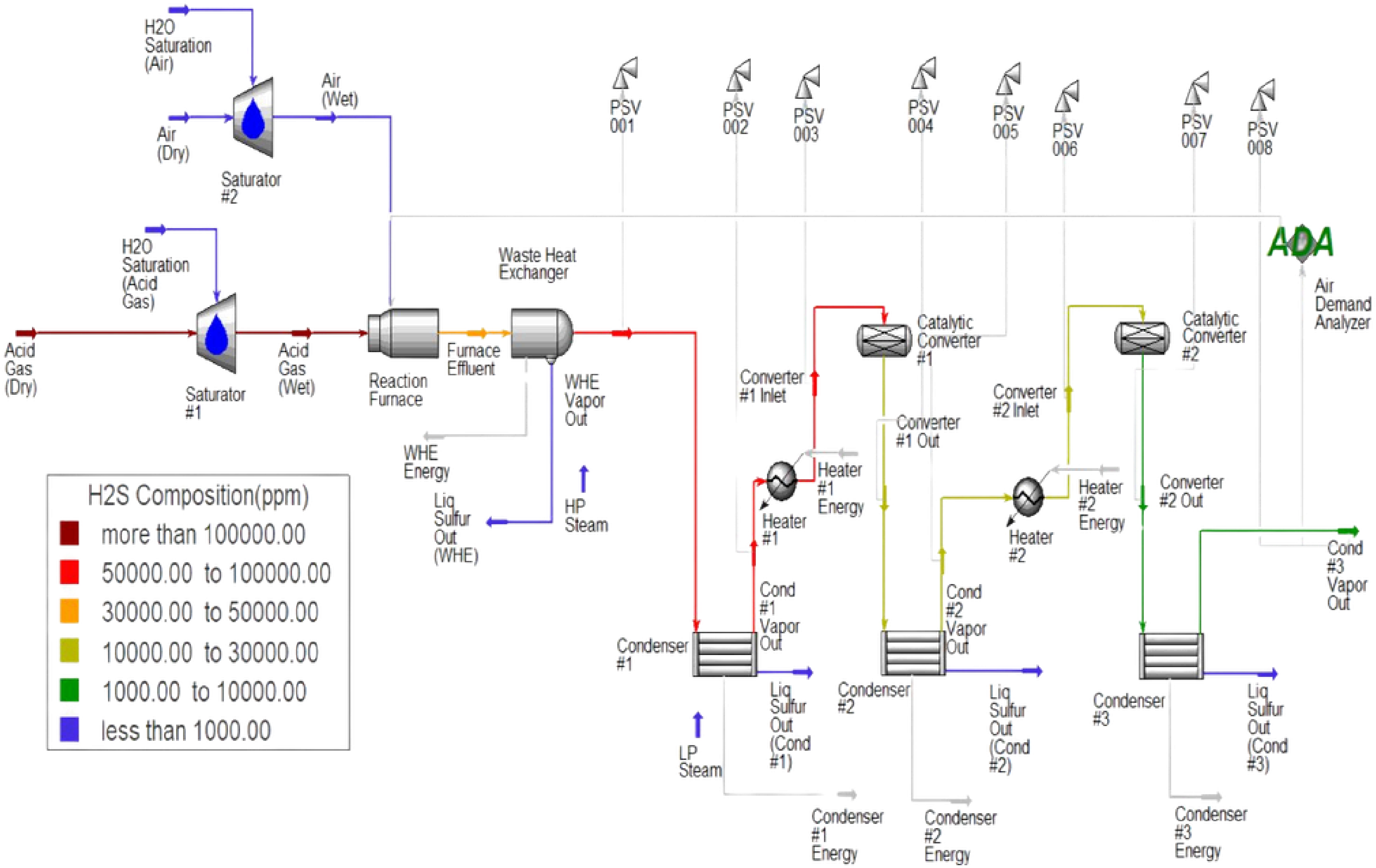
User Decision Effectiveness $\geq$ 92%



User decision effectiveness >=92%	**Met**

RESPONSIBLE DEPARTMENT: CHE
RESPONSIBLE STUDENT: JUMANAH RIFADAH & AFNAN ALQUBAYSI

PSV



$$A = \frac{Q_m}{\chi C_o K_o K_o P}\sqrt{\frac{Tz}{M}}$$

$$A = \frac{20723.45}{(346.64)(0.975)(0.0909)(1)(11)(1301.87)}\sqrt{\frac{(2545.47)(1)}{31.48}}$$

$$A \approx 2.009 \text{ in}^2$$

$$A = 2.009 \times 6.4516 = 12.964 \text{ cm}^2 \approx 12.97 \text{ cm}^2$$

Accurate PSV area sizing is essential for safe pressure relief and equipment protection.