Increasing the Understanding of the BP Texas City Refinery Accident

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Overview

- Description of the accident event
- Model of the accident event
- Dynamic simulation
- Analysis and discussion of inconsistencies respect to available literature reports
- Conclusions

Introduction

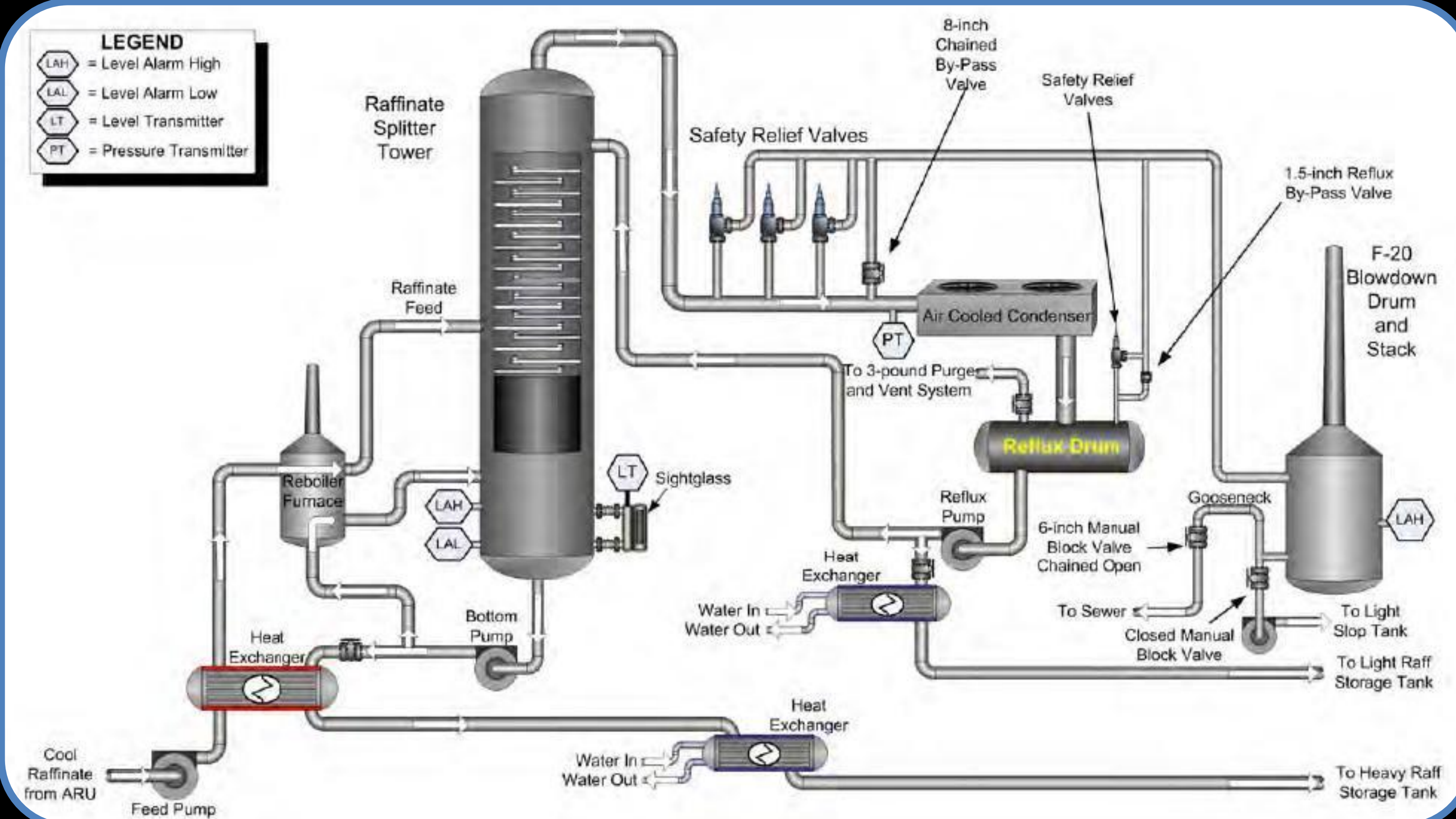
- **ACCIDENT EVENT**: explosion and fire during the startup of the isomerization unit of C6/C7 alkanes on Wednesday, March 23rd, 2005
- **CONSEQUENCES ON PEOPLE**: 15 fatalities and 180 casualties
- **ECONOMIC LOSS**: US$ 1.5 billion
- **LEGAL CONSEQUENCES**: a fine of US$ 87 million was inflicted to BP due to the violation of safety laws
- **PLANT SHUTDOWN**: 12 months (up to March 2006)

Scope of the work

ACCIDENT EVENT RECONSTRUCTION:

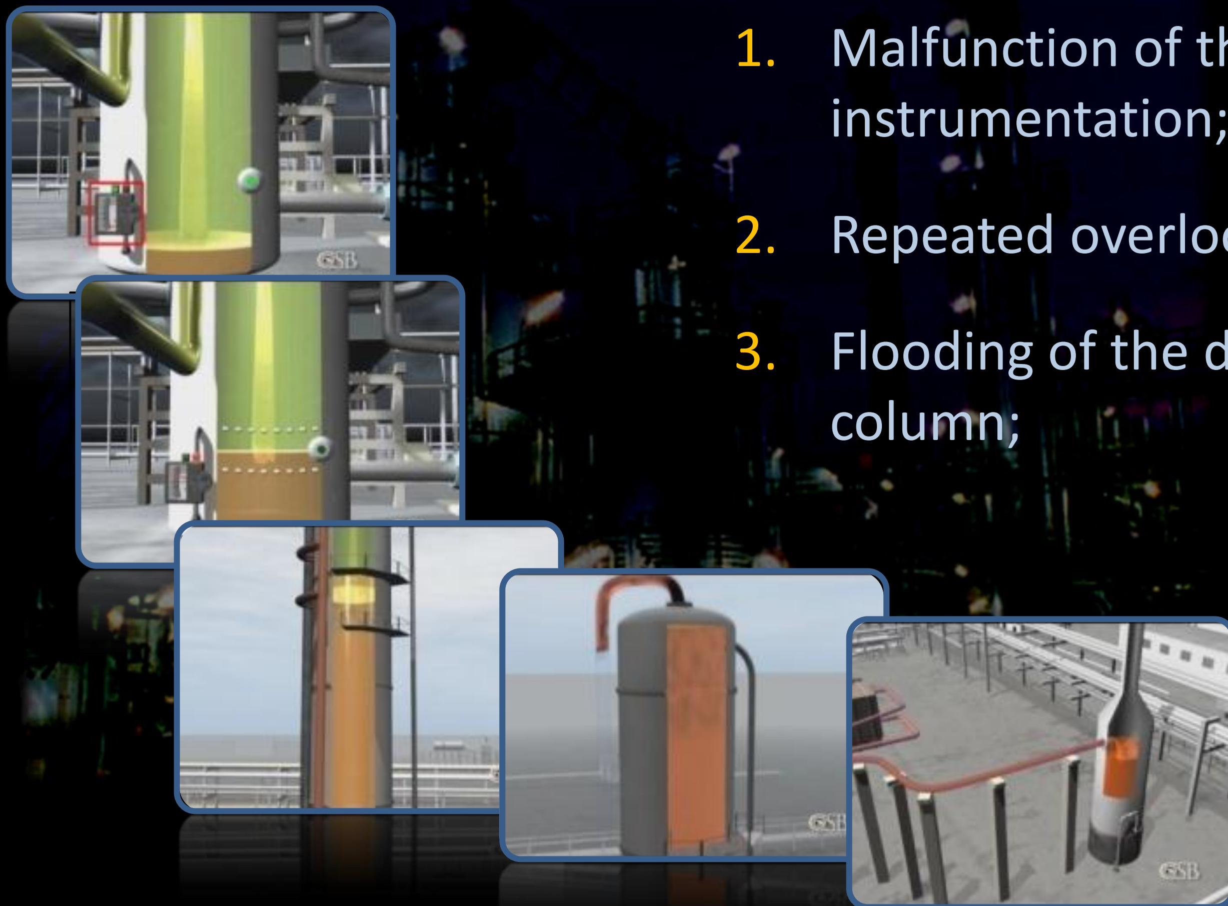
1. Analyze the **CAUSES**;
2. Study the **DYNAMIC EVOLUTION** of events;
3. Cover the **KNOWLEDGE GAPS** of literature reports and papers.

C6/C7 isomerization section



Source: U.S. Chemical Safety and Hazard Investigation Board (CSB)

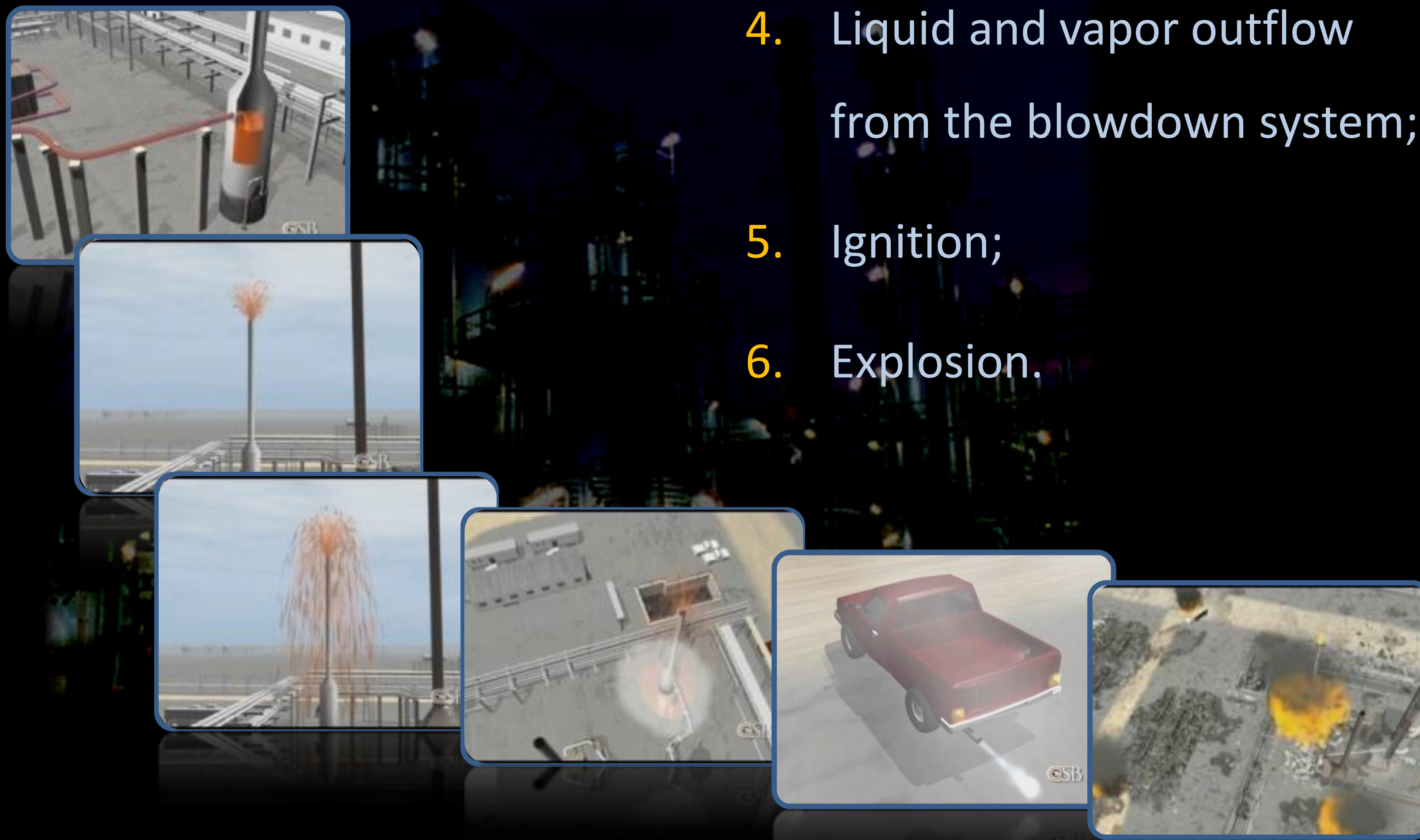
Timeline of the accident



1. Malfunction of the control instrumentation;
2. Repeated overlook of alarms;
3. Flooding of the distillation column;

Source: “Anatomy of a disaster” (www.csb.com)

Timeline of the accident



4. Liquid and vapor outflow from the blowdown system;
5. Ignition;
6. Explosion.

Source: “Anatomy of a disaster” (www.csb.com)

Gaps in the available literature

LITERATURE

- Mogford J., "*Fatal Accident Investigation Report, Isomerization Unit Explosion Final Report* ", (2005)
- CSB, "*BP Texas City Refinery Explosion and Fire – Investigation Report* ", (2007)
- Khan F. I., P. R. Amyotte, "*Modeling of BP Texas City Refinery Incident* ", J. Loss Prev. Process Ind., 20, 387-395, (2007)

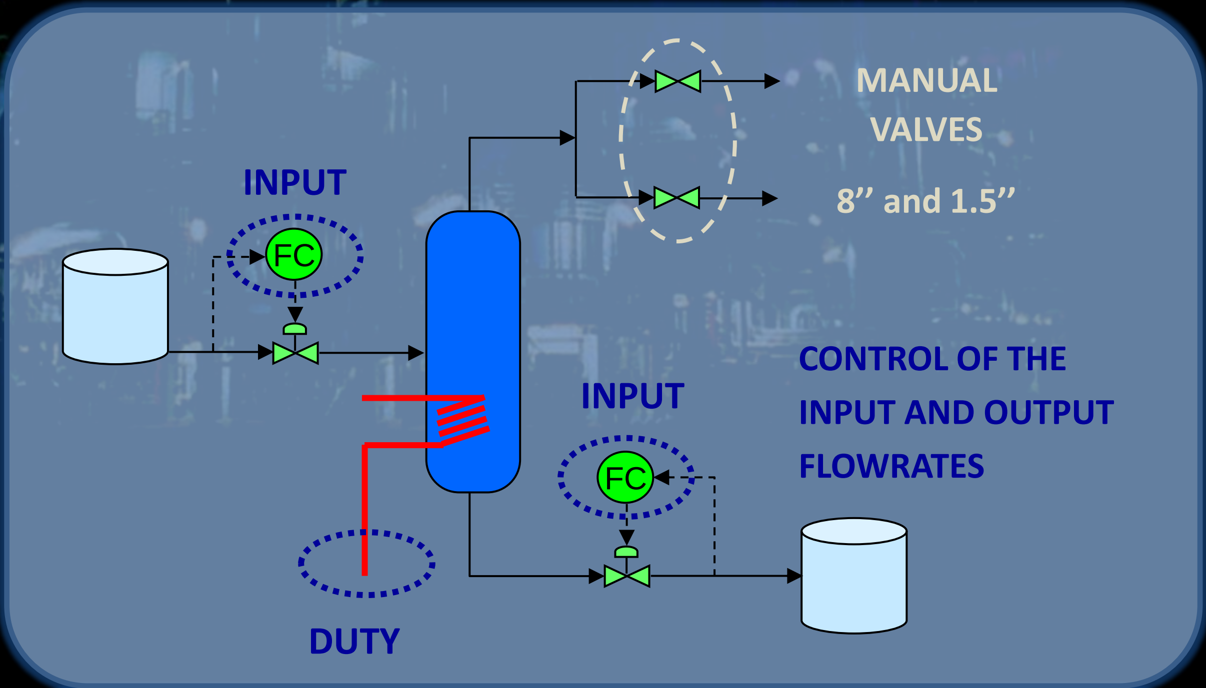
GAPS

- The real cause of the column flooding
- Missing analysis of the liquid-level dynamics inside the column
- Missing model of the dynamics of the fluid inside the blowdown duct
- The source of available data is not always clear and defined

It is therefore necessary to model the flooding of the column and the liquid-vapor transfer to the stack through the blowdown duct

Simulation of the column flooding

- The column was undergoing a startup procedure: no distillation operation was occurring.
- The column is modeled by a **TANK** whose volume is the same of the column once the volume taken up by trays is subtracted.



Timeline of the column flooding

02:18 am: start of feed to the column

03:20 am: suspension of startup procedure

09:52 am: restart of feed to the column

10:00 am: furnace startup. The bottom recycle is heated in the furnace

12:41 am: the operators open the 8’’ manual valve and close it at 12:55

12:55 am: the heavy raffinate is withdrawn from the bottom and preheats the feed to the column

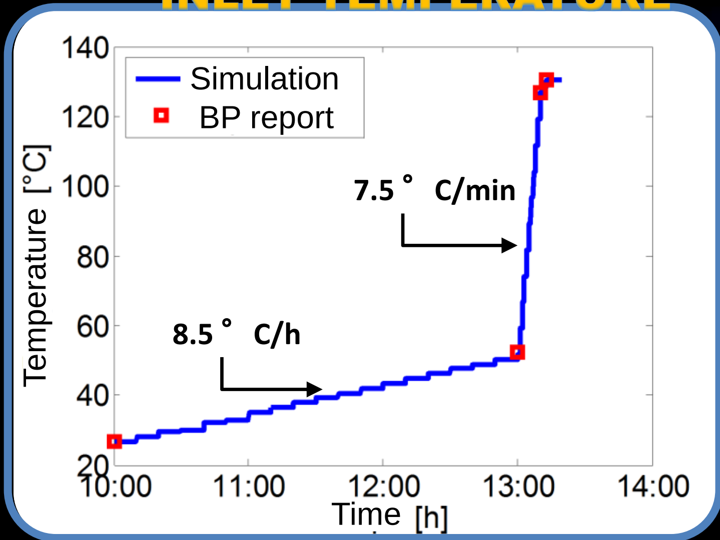
01:00 pm: the amount of bottom product becomes larger than the inlet feed

01:09 pm: the operators open the 1.5’’ manual valve
The resulting heating and the sudden depressurization take to the partial vaporization of the inlet feed

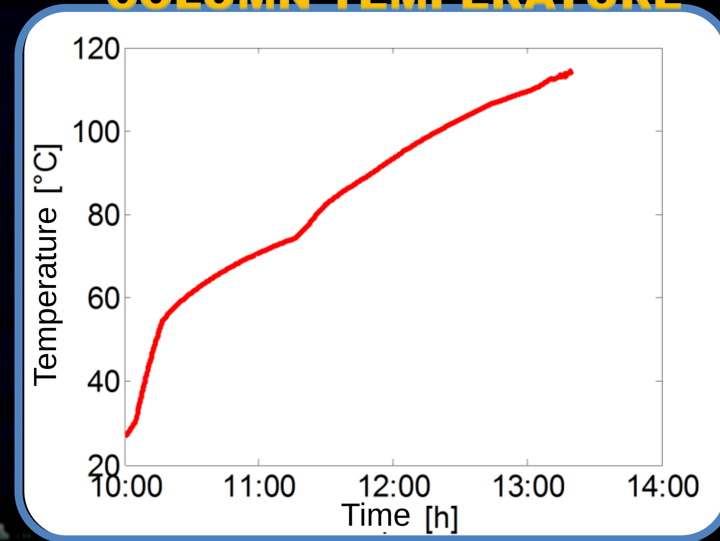
01:13 pm: flooding

Dynamics of the column flooding

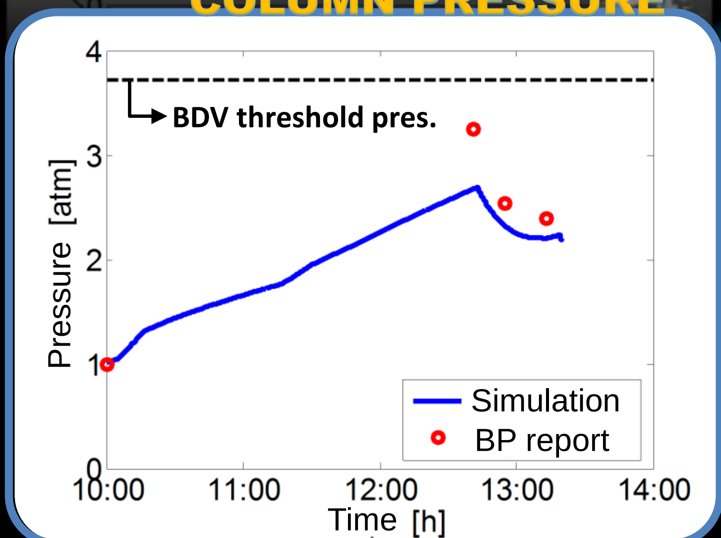
INLET TEMPERATURE



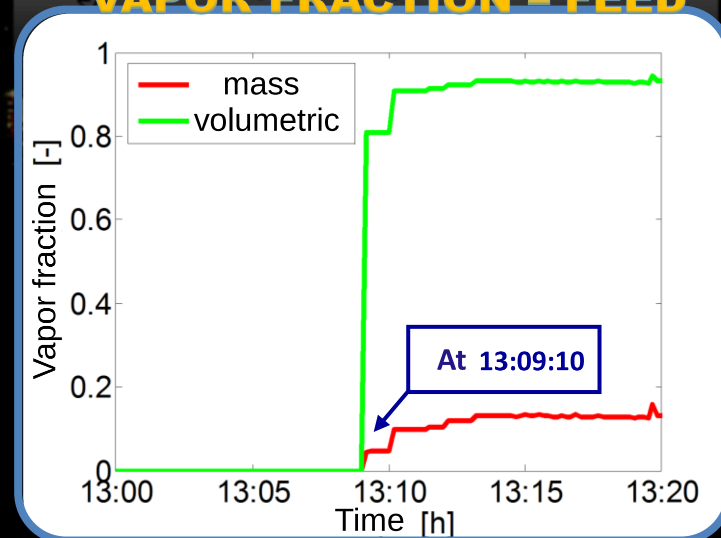
COLUMN TEMPERATURE



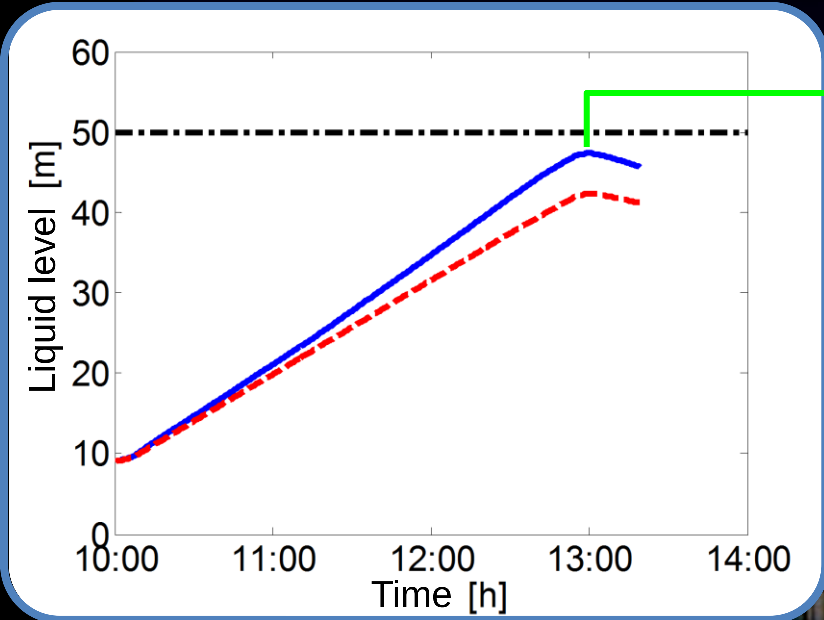
COLUMN PRESSURE



VAPOR FRACTION – FEED



Liquid level dynamics in the column



$F_{OUT} > F_{IN}$

At 1 pm: h = 47.39 m

At 1 pm: h = 42.37 m

+ 5.02 m (10.6%)

- The expansion of the liquid head cannot explain alone the final outflow from the top of the column.
- It is necessary to write a model for the bubble going up through the liquid head.

HYPOTHESIS

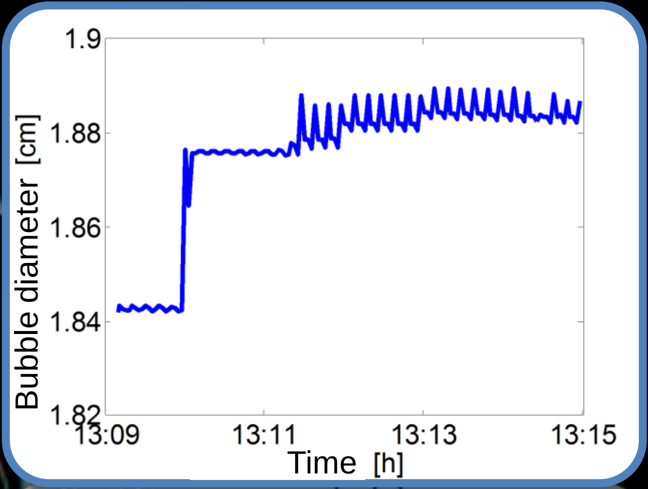
- EXPANSION OF THE LIQUID PHASE over the feed tray due to both the heating action and partial vaporization (*i.e.* bubbles presence)

Model of the column flooding

1. Bubble diameter

Tate's law (1864)

$$d_B = d_0 \sqrt[3]{\frac{6\sigma}{g\, d_0^2\, \Delta\rho}}$$



2. Upward velocity of the bubbles

Davies & Taylor (1950)

$$u_B = \frac{\sqrt{2}}{3}\sqrt{g\, d_B}$$

PROBLEM

- The bubble diameter depends also on the hole diameter of the trays
- $3\,\text{mm} \le d_{hole} \le 18\,\text{mm}$ **(Treybal, 1981)**

$$d_{bubble} \le d_{hole} \quad \Rightarrow \quad u_{bubble} = f\left(d_{hole}\right)$$

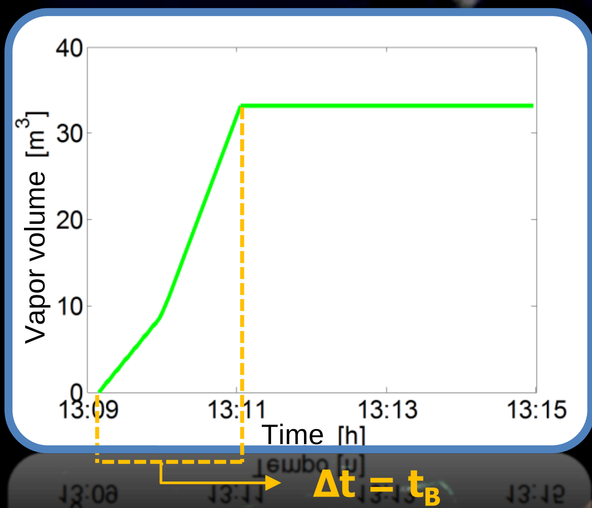
3. Rise time of bubbles

$$t_B = \frac{\Delta h}{u_B}$$

where Δh is the liquid head over the feed tray

Model of the column flooding

4. Overall bubble volume



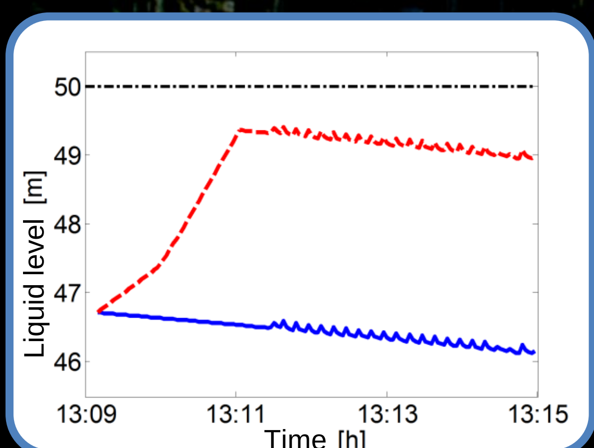
5. Liquid head of the mixture

$$h_{TOT}(t) = h_{LIQ}(t) + h_B(t)$$

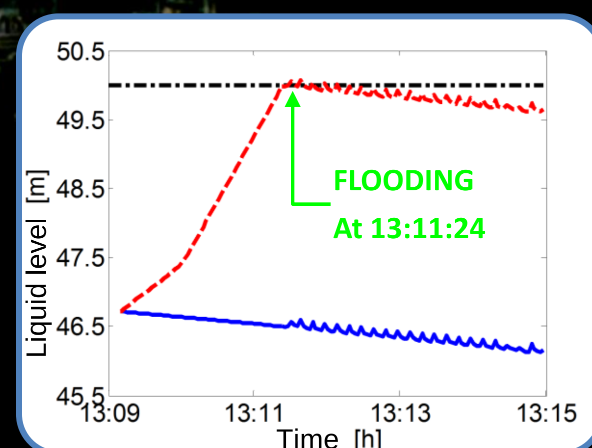
CRITICAL ANALYSIS

- **d_{hole} = 8 mm**:
  - ✓ There is flooding but not overflow
  - ✓ Over this diameter there is only flooding but no overflow
- **d_{hole} < 8 mm**: flooding and overflow

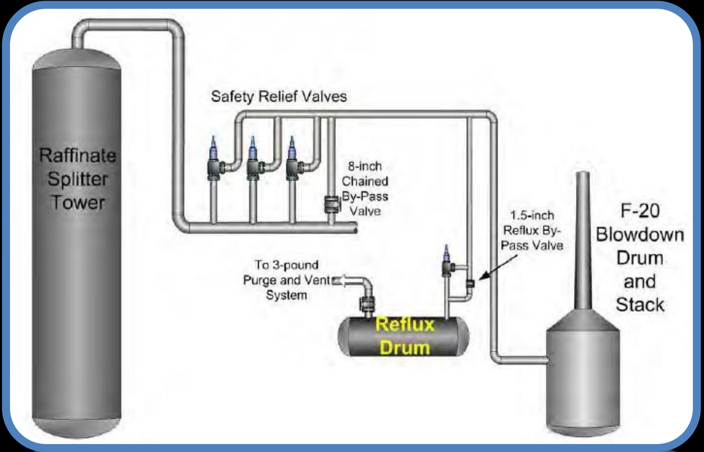
Case A: hole diameter = 10.5 mm



Case B: hole diameter = 8 mm



The blowdown system



OBJECTIVE

- Evaluate initial P and T that allow the fluid reaching the end of the blowdown duct

HYPOTHESIS

- P and T before the safety valves: **3.72 atm** and **112.4 °C**.
- Negligible pressure drops across the safety valves (once open)

ITERATIVE NUMERICAL PROCEDURE

- **Time discretization**: given a proper time interval Δt, we evaluate the dynamics of the fluid front:
  1. Mass flowrate (**G**)
  2. Fluid velocity (**u**)
  3. Distance (**Δx**)
  4. Pressure (**P**)
  5. Temperature (**T**)

STOP CONDITIONS

1. $\sum \Delta x(t) \geq L$
2. $P \leq P_{atm}$

Numerical procedure

1. Mass flowrate

$G = f(\Delta P)$ where $\Delta P = P - P_{atm}$

LIQUID MIXTURE

$$G = C_D \, \rho_L \, A \sqrt{2\left(\frac{\Delta P}{\rho_L}\right)}$$

TWO PHASE MIXTURE

HEM

(Homogeneous Equilibrium Model)

"Pseudo-monophase" fluid

$$\rho_F = \frac{1}{\frac{x_V}{\rho_V} + \frac{1-x_V}{\rho_L}}$$

$$G = C_D \, \rho_F \, A \sqrt{2\left(\frac{\Delta P}{\rho_F}\right)}$$

2. Velocity

$$u = \frac{G}{\rho \, A}$$

3. Distance

- we assume that the fluid moves at constant velocity within the time step
- the traveled distance during time step Δt is: $\Delta x = u \, \Delta t$

Numerical procedure

4. Pressure

- **Hypothesis**: concentrated pressure drops are negligible
- Distributed preessure drop ΔP along Δx:

Darcy Weisbach

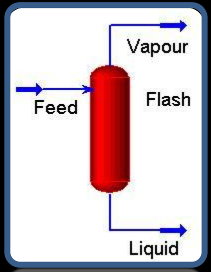
$$\Delta P = \Delta P_L = f_D \frac{\rho}{2} u^2 \frac{\Delta x}{D}$$

$$f_D = f(\mathrm{Re}, \varepsilon)$$

5. Temperature

- **Hypothesis**: the process is adiabatic
- The temperature is constant as long as the fluid is liquid and eventually starts decreasing as soon as the evaporation starts

EQUILIBRIUM TEMPERATURE
(adiabatic flash)

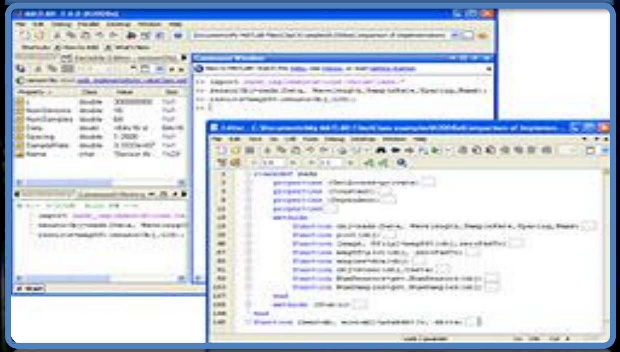


x_V → ρ_F ← x_L

Numerical procedure

VISUAL BASIC
(OLE Automation)

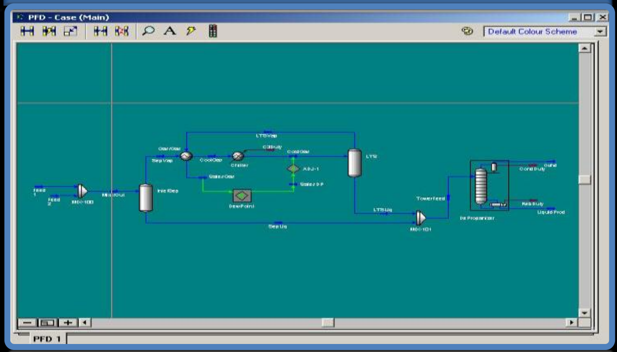
Numerical Engine



Pressure drops
Heat exchange
Two phase fluxes

Equilibrium temperature
L/V fractions

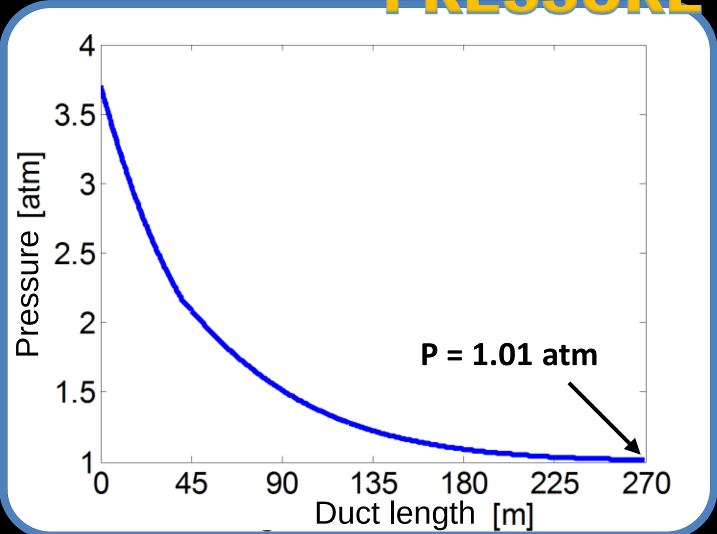
Detailed thermodynamic scheme



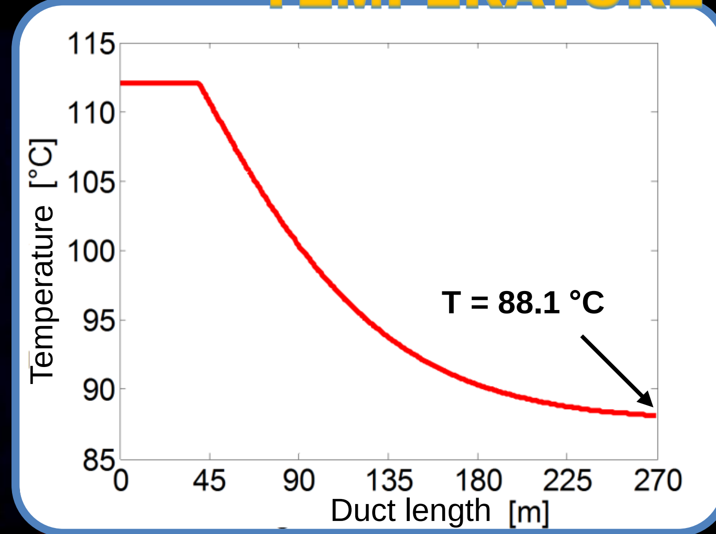
UNISIM®

Results

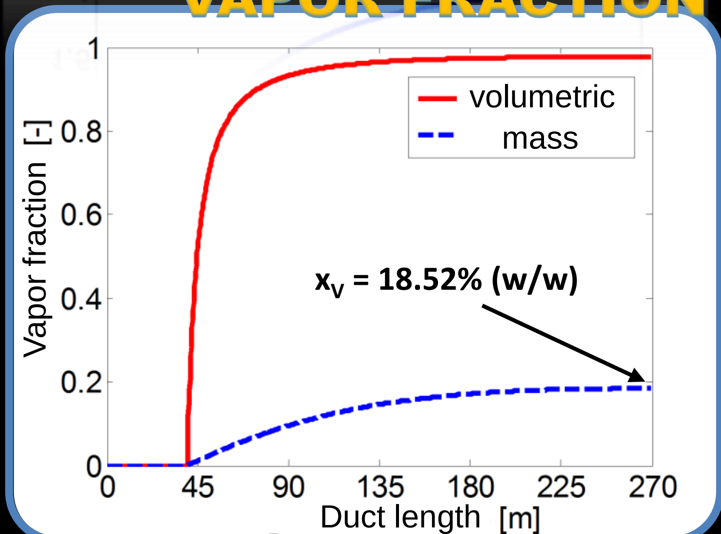
PRESSURE



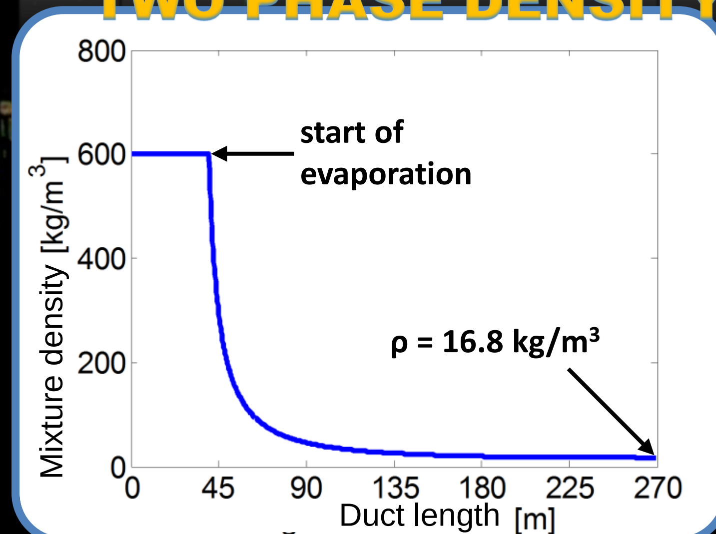
TEMPERATURE



VAPOR FRACTION



TWO PHASE DENSITY



Conclusions

- This presentation showed some innovative elements respect to available literature and reports;
- Evaluation of the liquid head in the column due to the thermal expansion and partial evaporation;
- Quantification of the volumetric expansion of the liquid phase and evaluation of the flooding dynamics in the column;
- The hypotheses adopted in the literature and in the reports are neither correct nor consistent.

FUTURE DEVELOPMENTS

- Detailed fluid dynamic analysis of the two phase mixture inside the blowdown duct;
- Modeling of the pool spreading, pool evaporation, gas dispersion, ignition, explosion, and pool fire.

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THANK YOU FOR YOUR KIND ATTENTION!