# Wind vulnerability model for components of refinery plants or industrial facilities: a preliminary study.

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***ABSTRACT***

The authors, with support from the Wind Hazard and Infrastructure Performance Center (WHIP-C), are developing wind vulnerability models of large industrial facilities like refinery plants. This research presents many challenges since these facilities are distributed over large plots of land which can have large variations in wind speeds, surface friction, topography, etc. At the same time, they can have a large variation in infrastructure components including power stations, pipe racks, tanks, warehouses, cranes, towers, etc. The authors propose to decompose the facilities into few sub-systems for which they can use conventional risk models: i.e., one site, one hazard, one vulnerability. Then they shall combine (not necessarily add) the models based on the inter-correlations between the sub-systems. In this so-called "Lego" approach, typical vulnerability components could be plugged in and interconnected, like Lego blocks, to produce an aggregated wind vulnerability of the whole system. The authors shall report on the preliminary results of the research, which involve extensive literature review, consultations with experts and the prioritization of certain sub-systems for in-depth analysis. Key topics include understanding wind-related damage, determining the most vulnerable equipment, exploring sources of contaminant leaks, and reviewing existing specifications and mitigation plans, and developing component-based wind vulnerability models for tanks and pipe-racks. The research aims to enhance preparedness and to assess the risk in the face of wind hazards for industrial facilities. Special attention is given to the link between wind hazard and Natech accidents (i.e. technological disasters triggered by a natural event, in this case a windstorm). Catastrophic wind events can result in failures of industrial components which in turn can lead to release of toxic substances and failure of safety systems. Proper modeling of the wind vulnerability of industrial plants should lead to better management of the Natech risk.

## *INTRODUCTION*

In the context of climate change and the increase in frequency and intensity of extreme weather events, assessing the vulnerability of critical infrastructures has become a priority. Refinery plants and industrial facilities, given their complexity and the diversity of components that make them up, present unique challenges in terms of modeling their vulnerability to wind. These facilities, spread over extensive land areas, are exposed to significant variations in wind speeds, surface friction, and topography, which further complicates their risk analysis.

The present research, with the support of the Wind Impact and Performance in Infrastructures Center (WHIP-C), proposes an innovative approach to address this issue. Through the development of wind vulnerability models for refinery plants and industrial facilities, this preliminary study aims to overcome the limitations of conventional methods. By decomposing the facilities into subsystems, a risk modeling methodology that considers the uniqueness of each piece of equipment as well as the associated vulnerabilities is applied. This approach allows for a more granular and precise risk assessment.

## *APPLIED METHODOLOGY.*

The proposed methodology is based on a systematic and structured analysis of wind vulnerability in refineries and other industrial facilities. The implementation involves various phases, summarized below, and detailed in the following sections of the publication:

- Comprehensive literature research: A comprehensive review of the existing literature was conducted to identify previous and advanced methodologies in risk and wind vulnerability assessment in industrial infrastructures. The following sections describe the outcomes of this search, which allowed for the determination of critical infrastructure components and understanding the limitations of previous and existing models.
- Consultations with Experts: Consultations were held to enrich the findings from the literature review and acquire practical knowledge on the challenges of modeling wind vulnerability in large-scale facilities.
- Subsystem decomposition: A modular approach, akin to "Lego" play, allows the integration of vulnerability components as blocks to generate an aggregated model of the entire system's wind vulnerability. Facilities are segmented into subsystems, which facilitates the application of conventional risk models (one site, one hazard, one vulnerability) to smaller and less complex components. Prioritizing specific subsystems also enables in-depth analysis, addressing critical aspects such as understanding wind-related damage, identifying vulnerable equipment, and reviewing existing mitigation plans.

***COMPREHENSIVE LITERATURE RESEARCH.***

## WIND-RELATED DAMAGE

The analysis of wind impact on industrial structures highlights the complexity and diversity of these systems. Unlike residential or commercial buildings, industrial facilities present significant variability in terms of susceptibility to wind damage. This is due to the diverse nature of their components, which may be located outdoors, indoors, or in hybrid locations. Moreover, the value of machinery and equipment, both mechanical and electrical, often far exceeds the value of the structures that house them, introducing a considerable level of risk and economic consideration in the management of these facilities. Stedman & Vojjala (2023), emphasize how, within a large industrial facility, structures like offices and warehouses may follow common conventions, but specific elements such as pipe racks and storage tanks present unique challenges due to their more nuanced components and different modes of failure. The importance of understanding these risks is amplified by the potentially serious consequences of physical damage, lack of accessibility, and safety shutdowns, which can have far-reaching effects.

## IDENTIFICATION OF THE MOST VULNERABLE EQUIPMENT

Cruz et al. (2001), and Liu et al. (2008), particularly highlight pipelines and connections between storage and process units as highly susceptible elements. High wind speeds can not only cause interruptions in the power supply or short circuits, triggering failures in steam boilers and cooling towers but can also lead to the release of hazardous materials. The wind's ability to turn everyday objects into projectiles capable of damaging equipment, breaking pipelines, and perforating tank roofs underscores the complexity of the risks associated with severe wind events.

On the other hand, Misuri et al. (2019), have contributed findings that underscore the exposure of storage tanks to direct structural damage, which could result in the release of hazardous substances. The importance of these tanks as critical assets in chemical release scenarios is doubly emphasized due to their inherent structural vulnerability and the significant amount of hazardous chemicals they contain. In this context, the guidelines provided by the Federal Emergency Management Agency (FEMA) regarding required actions during emergencies, particularly in terms of the preventive shutdown process, become essential for the industry.

## COMPONENT-BASED WIND VULNERABILITY MODELS

A component-based methodology has been developed that addresses the vulnerability and susceptibility to damage of essential components in various types of large industrial facilities. According to Stedman & Vojjala (2023), it is vital to precisely quantify the vulnerability of these valuable facilities, as any damage implies not only considerable economic losses for stakeholders but also, in cases of oil refineries or power generation facilities, can cause extensive secondary effects that impact entire regions or countries.

Furthermore, Omidvar (2023),points out that vulnerabilities in the oil and gas sector are diverse, being exposed to a wide range of natural hazards and human activities. In the following sections of their analysis, it is argued that, although these sectors are susceptible to natural hazards and certain types of activities, the implementation of prevention and adaptation methods can not only mitigate risk and vulnerability but also strengthen the resilience of these critical infrastructures. These multidimensional approaches are fundamental to ensuring operational continuity and environmental protection in the context of effective risk management.

## ***CONSULTATIONS WITH EXPERTS***

Throughout this study, a dialogue was facilitated with subject matter experts, during which findings obtained from the literature review were presented and deliberated. During these discussions, various basic topologies applicable to specific elements within the industries, such as tanks and pipelines, were exposed.

The proposed topologies emerge from an analysis of the prevailing standards in the industries, which are a fundamental prerequisite before proceeding with the selection or design of a facility. Among the most recognized standards are those of the ASME (American Society of Mechanical Engineers), API (American Petroleum Institute), and OSHA (Occupational Safety and Health Administration), among others. These standards, which consolidate a multiplicity of decisions within the industrial scope, have been the starting point for the detailed development of tanks and piperacks. However, this document will focus exclusively on presenting a fraction of the topology concerning tanks.

A significant consensus was reached among the experts regarding the identification of equipment most prone to vulnerabilities, which largely aligns with the information reported in the consulted bibliographic sources. Specifically, it was agreed that the facilities most affected are tanks and pipelines.

Furthermore, the possibility of developing a standardized typology for refineries was investigated. However, this effort faced considerable challenges due to the inherent complexity of the diversity of factors, processes, and products present in the operations, which hinders the formulation of a unified classification.

The deliberations concluded with a unanimous agreement on the critical importance of developing a framework that enhances the understanding of the interactions between different pieces of equipment within the facilities. This in-depth knowledge is key to enriching our understanding of the overall operability of refineries, highlighting the urgency of adopting a holistic approach. Such an approach would facilitate the identification of potential vulnerabilities, allowing for the implementation of more effective mitigation strategies.

A primary distinction was established in the first hierarchy of the decision tree, differentiating between tanks that operate under pressure and those at atmospheric pressure, as can be seen in Figure 1.

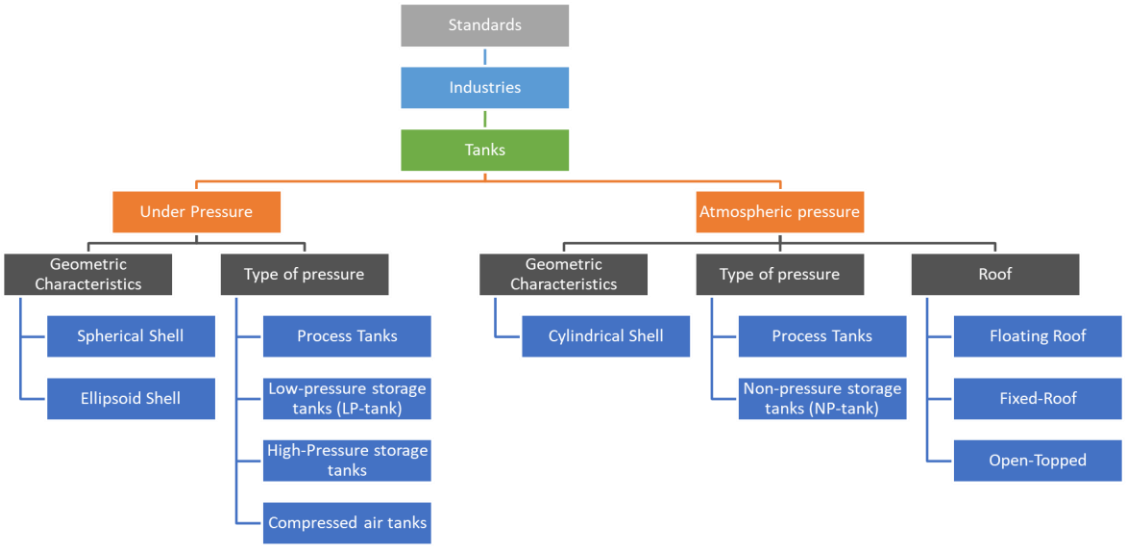


**Figure 1: General Topology of Tanks**

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## ***PRELIMINARY RESULTS***

Given the impossibility of generating a virtual or schematic representation of a refinery or industry that is simultaneously applicable in multiple locations, the search for relevant documentation was undertaken to unify industrial criteria and identify both the equipment and their interrelationships. In this process, the importance of a type of documentation known as the Process Flow Diagram (PFD) was highlighted. This document is of vital importance and provides significant value, as it is not only one of the first to be developed in the initial stages of a project but also serves as one of the main reference documents, being responsible for detailing the flow of materials through the industrial process. For the development of this conceptual framework, the schematic view provided by the Occupational Safety and Health Administration (OSHA) of the United States government was chosen as a reference. This scheme is illustrated in Figure 2.

Using the schematic representation provided in Figure 2, it was possible to delineate 71 integral processes, ranging from the input of crude oil to the output of the finished product from the facility. Graphically, **¡Error! No se encuentra el origen de la referencia.** synthesizes this content, facilitating an overview of it. The added value of this table lies in its ability to allow users a quick identification of the equipment that makes up the refinery in question. Concurrently, in the course of developing this table, 64 different interactions between the equipment were identified, information of utmost importance to support our ongoing initiatives.

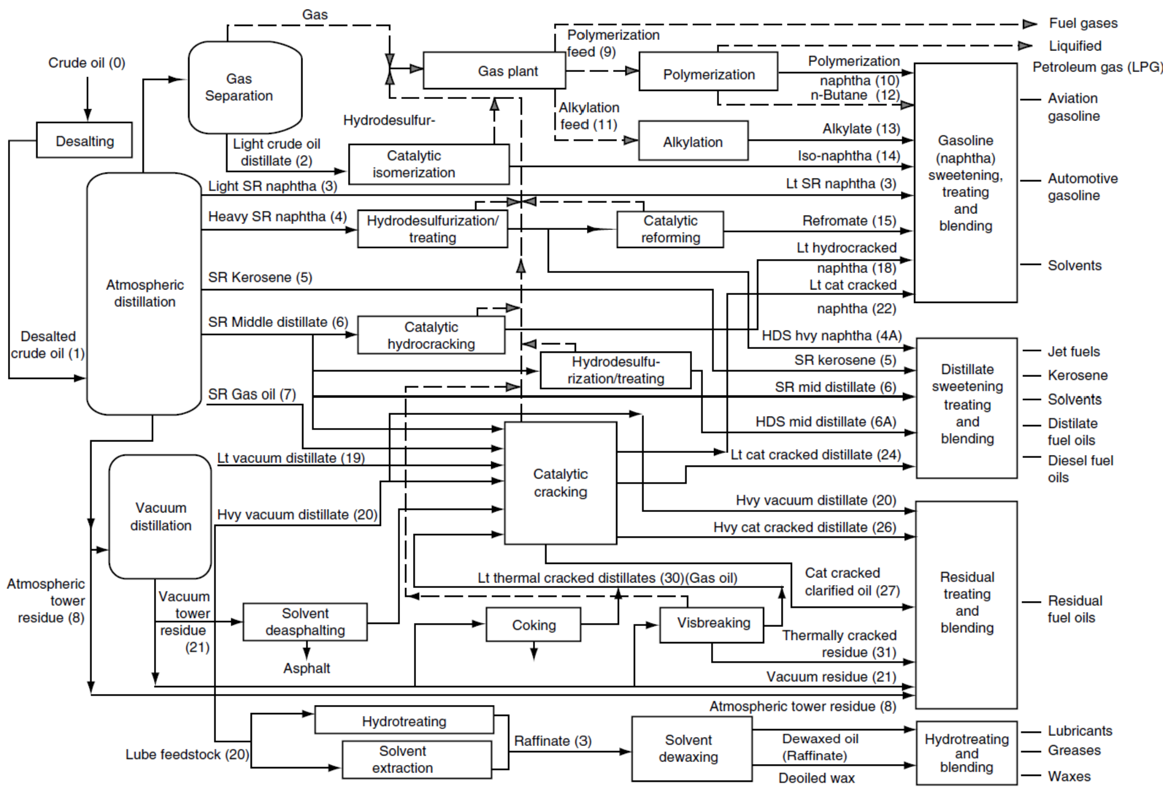


**Figure 2: Schematic View of a Refinery. OSHA Technical Manual, Section IV, Chapter 2, Petroleum Refining Processes. Speight J., The Chemistry and Tecnology of Petroleum (2006)**

The aim of **¡Error! No se encuentra el origen de la referencia.** is to facilitate the rapid identification of the equipment that comprises the infrastructure of a refinery. This resource has been developed with great precision in detail, ensuring that each item corresponds clearly to the relevant equipment. The table is intended to be used by insurance companies and industries seeking to assess and discern their operational vulnerabilities. The relevance of the information contained in the table is significant, as it reveals the interconnections between the equipment and the logic inherent in the development of process flows and the identification of internal risks.

In conclusion, the table in question provides a detailed representation of the equipment involved in the refining process, as well as the existing interconnections between them. The main focus of this tool is to facilitate a comprehensive vulnerability analysis through the "Lego" methodology, which allows for a systematic and modular inspection of each piece of equipment and its corresponding interactions. This modular approach is not only ideal due to its applicability but also for the flexibility it offers in examining each component individually.

**Table 1: Summarized Representation of the Operational Sequence in Refineries**

| Final Product | Previous Process | Previous Process 2 | Previous Process n | Raw Material |
|---|---|---|---|---|
| **Automotive gasoline** | Sweetening, treating and blending | Catalytic Isomerization | … | Crude Oil |
| **…** | … | … | … | Crude Oil |
| **Kerosene** | Sweetening, treating and blending | Atm. Distillation | … | Crude Oil |

## ***DEVELOPMENT INITIATIVES***

In the process of developing our risk model, we still need to specify what the specific inputs will be. It is imperative to perform a comprehensive analysis to determine if the Process Flow Diagram (PFD) we have, accompanied by a complete inventory that we must develop, including all possible components, will be sufficient to define the industry's exposure to relevant risks.

Acquiring in-depth knowledge about the equipment, their characteristics, and the variety of their attributes is an essential premise for our project. On the other hand, the meticulous identification of each component's key characteristics is an invaluable task. Recognizing and documenting these critical aspects will allow us to focus our efforts on collecting accurate and relevant data. This process is of vital importance and will directly impact the integrity and effectiveness of our risk model, thus ensuring its applicability and reliability.

Development of component-based vulnerability models: For priority subsystems, such as tanks and pipe racks, specific wind vulnerability models will be developed. These models will be based on the evaluation of design characteristics, construction specifications, and potential failure modes in the face of extreme wind events.

Integration of subsystem models: The vulnerability models developed for the various subsystems will be integrated, considering the interrelations among them, to generate a comprehensive wind vulnerability model for the entire facility. This process will include the evaluation of interaction effects and the accumulation of risks among the infrastructure components.

Model validation: The model will be validated by comparing its results with data from historical wind events and feedback from involved experts. This step will ensure that the models are realistic and accurately represent the vulnerability of industrial facilities to wind.

## ***CONCLUSION***

After identifying storage tanks and pipe racks as critical components, there is still a long road ahead. The increasing frequency of adverse natural events, the consequent material losses, and the need for advancements that move in unison are evident. It is imperative that both insurers and the insured operate in an environment of reduced uncertainty and make informed decisions regarding their capital invested in machinery and infrastructure.

So far, we have learned that refineries do not adhere to a pre-established design; rather, their configuration is adjusted according to available spaces and specific requirements. In turn, although these facilities process the same raw material, such as crude, and produce identical products, such as jet fuel, they will not necessarily have the same installations. This variability complicates the task of characterizing the industry, as there are no uniform elements available for this purpose. The document closest to a characterization tool is the Process Flow Diagram (PFD), which provides a representation of the plant's operational flow.

There has been identified a need to develop a specific tool that facilitates the analysis of this type of industry, allowing the identification of its spatial arrangement to fully understand the refinery. It was observed that, although many studies focus on tanks, these are merely isolated components that do not reflect the complexity of the relationships within a refinery.

## ***ACKNOWLEDGEMENTS***

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