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Polyester Reçine Üretim Tesisinde Fonksiyonel Rezonans Analiz Yöntemi (FRAM) ile Risk Analizi

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Araştırma Makalesi

Öz- Polyester reçine üretim tesislerinde iş akışı süreçlerinde çeşitli tehlikeler ve riskler bulunmaktadır. Bu tehlike ve risklerin en önemlileri; Elde edilen ürünlerin kimyasal prosesleri, yangın ve patlama, ekipman arızaları ve depolama süreçleri ile ilgilidir. Bu çalışma, Marmara bölgesindeki bir polyester reçine üretim tesisinde, hammaddenin tesise gelişinden, işlenmesi ve ortaya çıkan ürünlerin depolanmasına kadar karşılaşılabilecek potansiyel tehlike ve risklerin Fonksiyonel Rezonans ile analiz edilmesini amaçlamaktadır. Analiz Yöntemi (FRAM) ve süreçlerin optimize edilmesini engelleyen aşamaların belirlenmesi. Hem iş akışı süreçlerinin iyileştirilmesine hem de süreçteki risklerin azaltılmasına yönelik önerilerde bulunulacak şekilde hazırlanmıştır.

Anahtar Kelimeler *– polyester, reçine, risk, tehlike, FRAM*

Risk Analysis in Polyester Resin Production Facility with Functional Resonance Analysis Method(FRAM)

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Research Article

Abstract – There are various hazards and risks in the workflow processes in polyester resin production facilities. The most important of these dangers and risks are; It is related to chemical processes, fire and explosion, equipment malfunctions and storage processes of the products obtained. This study aims to analyze the potential hazards and risks that may be encountered in a polyester resin production facility in the Marmara region, from the arrival of the raw material to the facility, to its processing and storage of the resulting products, with the Functional Resonance Analysis Method (FRAM) and to identify the stages that prevent the processes from being optimized. It has been prepared to make suggestions both for improving workflow processes and reducing risks in the process..

Keywords *–polyester, resin, risk, danger, FRAM*

1. **INTRODUCTION**

1.1. **Information About Polyester**

The word polyester is a compound word consisting of the word's poly, meaning many, and ester, a term used to indicate organic salt. Therefore, polyester can be defined as various organic salts. The ester molecule chains of the structure can also be defined as polymers. Polyesters occur in nature, but generally include a large family of synthetic polyesters, which includes all polycarbonates and polyethylene terephthalates. Polyester is abbreviated as PES (Yakartepe, 1997).

In polyester production, pure terephthalic acid and monoethylene glycol, which are petroleum derivatives, are used as raw materials, and antimony triacetate and titanium dioxide are used as auxiliary materials (Çelebi, 2009). Polymerization of terephthalic acid with ethylene glycol is the most common method used in polyester production (Kara, 2011). Polyesters are indispensable and important polymers with many properties such as hardness, weather resistance and resistance to various chemicals. In general, polyesters are obtained by processing polyfunctional acids, mostly dibasic acids, polyalcohols such as glycol and glycerin, or monomers such as methyl methacrylate, styrene and diallyl phthalate (Viksne, 2002). Styrene, the main component of polyester resins, is a slightly toxic material that evaporates during the reaction. For this reason, it poses a danger to those working in this field if inhaled (Sınıksaran, 2012).

The first synthetic PES in history was made during the First World War, using the chemical glycerin phthalate to achieve waterproof properties. The most comprehensive research on polyester is the research conducted by DuPont© company on polymers (Çirkin, 2006).

Polyester resins; They are polymeric materials formed as a result of the reaction of multifunctional acids (dicarboxylic acid) and multifunctional alcohols (glycol). Polyester resins are almost colorless liquids that are thick and difficult to flow. They can come in different forms such as liquid, gel and film. The lightness and weather resistance of polyester resins are used in different industries, from composite materials to aviation, from transportation to construction, from furniture to packaging and the manufacturing sector. One of the areas where polyester resins are most used is the casting industry. Casting resins are soft and flexible. Casting type polyesters are mostly; Bathtubs, sinks, artificial marble, kitchen countertops, table edges and legs, ornaments, roof coverings, souvenirs, sculptures, handicraft products, fillings, automobile and boat parts and sanitary ware, etc. used in production. Polyester resins are classified as saturated and unsaturated according to their chemical structure (https://webdosya.csb.gov.tr; www.craftyapi.com; Akın, 2007).

In saturated polyester resins, the reaction is saturated and balanced. That is, its molecules do not tend to bind to other molecules. These are polyester resins with saturated carbon atoms formed as a result of the polymerization reaction. Such resins usually contain methylene groups (CH2). The best example of saturated polyesters is plastic beverage bottles (PET). This material shows plastic properties and melts when heated and can be reshaped (https://www.kompozit.org.tr; https://webdosya.csb.gov.tr).

In unsaturated polyester resins, the molecules are not fully saturated due to chemical instability. These unsaturated bonds usually belong to vinyl or alkene groups and can form cross-links during polymerization reactions. Since they have carbon-carbon double bonds in their structure, when they harden, they form a network structure and become a hard and solid material that cannot be recycled. Examples of unsaturated polyester: bathtubs and kitchen countertops (https://www.kompozit.org.tr; https://webdosya.csb.gov.tr).

More than 0.8 billion kg of polyester resin was consumed in the United States in 1999. Polyester resin composites are low cost. Because it has cheap installation costs and durable physical properties in certain applications. Advantages of polyester resin matrix composite materials; finished parts can be hardened in different ways without changing their physical properties. Therefore, polyester resin composites have the features to compete in special markets. In addition, its wide usage area, dimensional stability and affordable prices increase its competitive features (Miracle, Daniel B., Donaldson, Steven L. 2001; Bagherpour, 2012; Park, 2011).

Polyester resins are the locomotive of the composite industry and constitute approximately 75% of the resins used (Akın, 2007). Polyester resins are formulated to achieve the desired properties and suit the molding process. Because polyester resins are versatile and can be modified and shaped during the formation of polymer chains, they have unlimited applications in almost all segments of the composite industry. Polyester resins have good mechanical and chemical resistance below 100 0C and their prices are low. Polyester resins are also classified as general or special purpose polyesters according to their intended use (Yılmaz, 2006).

General purpose polyesters are defined as products that are inexpensive and provide adequate mechanical and electrical performance. General purpose polyesters are produced in medium or low viscosity and require only the addition of catalyst and accelerator. Except for expensive applications where better performance is not expected; It is used in the production of final products made by open molding in a wide range of products, including automobile parts, pipes, construction panels, electrical products, boats, general truck parts, furniture, bathtubs, containers, engines, machines and other products (Yılmaz, 2006). General Purpose Polyesters are the resins with the highest commercial volume and the lowest cost (Ergin, 2005).

Special purpose polyesters; Because polyesters are produced through a chemical process to meet the requirements of many applications, polyesters are available for different purposes. Examples of special purpose polyesters: Polyesters that provide flexibility, chemical resistant polyesters, heat resistant polyesters and flame-resistant polyesters (Yılmaz, 2006).

2**. Hazards and Risks in Polyester Resin Production Facility**

There are various hazards and risks in the workflow processes in polyester resin production facilities. Potential hazards and risks that may be encountered in these facilities are as follows;

1-Chemical Hazards; Dangerous situations may arise depending on the properties of the chemicals used (reactive, flammable, toxic). The use and storage of chemicals such as volatile organic compounds, acids and bases, monomers, catalysts and solvents can be hazardous. Various chemicals may be released into the environment as a result of leaks that may occur in reactors or pipes. This may cause workers to be poisoned by inhalation or skin contact, and may cause an explosion in the facility for various reasons.

2-Fire and Explosion Hazards; The high temperature and pressure that may occur during the reaction in reactors and blenders can increase the risk of fire and explosion. There is always a risk of explosion and fire during the processing of chemical materials in production processes and the storage of the resulting products. In addition, there is always a risk of explosion during the transportation of materials with forklifts due to static electricity accumulation and employees' failure to comply with safety procedures and incorrect use of work equipment.

3-Equipment Malfunctions; Malfunctions that may occur in equipment such as reactors, blenders, pumps may cause chemical leaks and leaks, so employees may be affected by chemical gases. Defective equipment may cause overheating and sparking, which may interact with flammable materials and increase the risk of fire and explosion. Malfunctions that may occur in reactors and pressurized equipment may bring the risk of explosion. There is always a risk of leakage and explosion due to malfunctions that may occur in the pipes during the flow of materials in the pipelines.

4-Ergonomic Risks; Repetitive movements in production processes, lifting heavy loads, and working in fixed and challenging postures for a long time can lead to back and neck pain and musculoskeletal diseases. High noise levels within the facility can cause employee hearing loss. The designs of tools and equipment used in production processes may not be ergonomic for employees. This may cause physical discomfort in employees. Heat, cold or humidity in the working environment can negatively affect the performance and health of employees.

These hazards and risks can be managed by applying methods such as implementation of appropriate safety measures and procedures, periodic maintenance of equipment, inspections, and training of employees (Anonymous, 2023).

3. **Precautions to be Taken in Polyester Resin Production Facility**

Precautions to be taken against potential hazards and risks in polyester resin production facilities; It includes a set of safety protocols to ensure both worker safety and environmental safety. The basic precautions to be taken in these facilities are as follows;

1-Personnel Training; All employees should be trained regularly on occupational health and safety. Training should be provided on the correct use, storage and processing of chemicals. These trainings are important to reduce the risk of exposure to chemical substances and to prevent the formation of a flammable and explosive environment in the facility. Training should be provided on the safe and correct use of machinery and equipment used in the facility, and this training should be updated under changing conditions. Staff training programs should be updated when workflow processes or security standards change. Additionally, training should be provided on emergency procedures and the use of personal protective equipment.

2-Personal Protective Equipment; Workers should be provided with appropriate personal protective equipment, they should be taught how to use the personal protective equipment they need to use during work correctly, and the use of this equipment should be encouraged. For example, respiratory masks, protective suits, goggles, etc. Personal protective equipment should be stored under appropriate conditions and maintained regularly.

3-Emergency Plans; Before creating an emergency plan, a risk assessment analysis should be performed to determine potential hazards and risks in the facility, and this risk assessment analysis should be updated within the periods specified in the regulation and after any changes that may occur in the workflow processes in the facility. The facility must be prepared for emergency scenarios such as fire, explosion, chemical leaks and pressure equipment failures. This is very important for the safety of employees and the continuation of workflow in the facility. Emergency teams should be formed for emergency scenarios and team members should be trained on job descriptions. Employees should be run through drills regularly to test emergency plans.

4-Warning and Safety Signs; Appropriate warning and safety signs should be affixed to hazardous areas within the facility. The reason for this is to create risk awareness among employees. In order for employees to recognize environmental risks, appropriate warning and safety signs must be hung in designated places to identify chemical storage areas, hazardous equipment, factors that may cause fire and explosion, and hazardous areas. Proper use of warning and safety signs within the facility is crucial to increasing safety in the workplace and reducing potential risks.

Taking these precautions, making updates to relevant areas in case of changes that may occur in workflow processes, and regularly monitoring the processes are important to ensure a safe working environment in polyester resin production facilities (Anonymous, 2023).

4. **Material and Method**

In this study, potential hazards and risks that may occur in the workflow processes of a polyester resin production facility in the Marmara region were determined by taking the opinions of the employees and analyzed with the Functional Resonance Analysis Method (FRAM).

The FRAM method is an analysis method developed by Erik Hollnagel. It is an analysis method used to understand errors in complex systems and evaluate risks related to occupational safety. FRAM method; It helps identify potential risks by analyzing interactions and dependencies within a system. It focuses on identifying critical points for security by examining workflow processes in an organization in detail. It is important for occupational safety due to its ability to adapt to changing conditions and system dynamics. FRAM is a method used in industry, healthcare and similar complex systems (Hollnagel, 2012; Patriarca, 2017). It has six main parameters. These parameters are used to analyze a system and understand the functioning of the system. These parameters; They are Input (I), Output (O), Precondition (P), Source (R), Time (T) and Control (C). Input (I): It refers to the information, material or other resources entering a system or system component. Outputs (O): These are the results that occur after the successful completion of the functions in the system. These outputs provide information about the state and interactions of the system after the completion of the process or function. Resources (R): These are the elements that make up the system and contribute to the realization of processes. These elements are generally employees, equipment, information, time and other physical resources. Controls (C): These are the arrangements used to prevent or manage undesirable situations in the system. These control mechanisms are applied to ensure that processes operate safely, effectively and as desired. Preconditions (P): These are the initial conditions required for a process to start or a function to occur. Time (T): It is the time taken during the beginning, operation and completion of a process. It is evaluated to understand how long a function takes to occur and at which stages and in what time periods interactions occur (Aydın, Can, İltar, Kara, 2022). FRAM steps are shown in Figure 1.

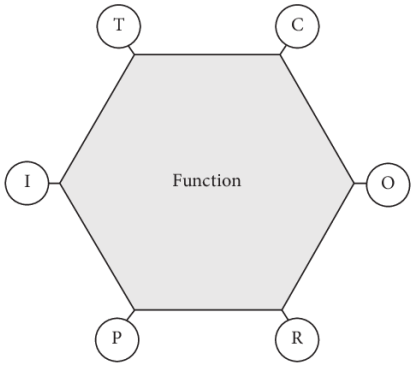

Figure 1. Hexagonal function representation (Hollnagel, 2012)

Research Findings

After conducting a literature review and taking the opinions of the employees, the 5 main functions of the system, including input, output, source, control, precondition and time steps, are defined in Table 1 in the first stage of the FRAM case application.

Table 1. System Functions

Function Number	Function Name	Input(I)	Output(O)	Source(R)	Precondition(P)	Control(C)	Time (T)
1	**Freight Elevator**	**Overload**	**Training** **instruction** **Raw materials** **Fault**		**standards** **Not to be used by Unauthorized Persons**	**Periodic check-up**	
2	**Periodic check-up**	**Fault**	**Fire** **Overload**	**handling equipment** **electrical installation** **Ventilation** **Compressor**	**Exproof equipment** **Not to be used by Unauthorized Persons**	**Standards** **Alarm system** **Instruction**	
3	**Reactor**	**Overload** **Raw materials**	**Fire** **intermediate product**	**exposure**	**Training** **Exproof equipment** **static sheet** **insulation** **KKD** **hot surface**	**Storage Matrix** **Alarm system**	
4	**Blender**	**intermediate product**	**Polyester**			**exposure** **Alarm system**	
5	**Storage**	**Polyester** **Training** **KKD**	**Storage Matrix**		**Ventilation**	**Alarm system**	

Definitions of 4 scenarios that are thought to affect the workflow process are given in Table 2. The variables in Table 2 and their effects on these scenarios are defined.

Table 2. Scenarios

No	Scenario	Variable	Effects of Variable
1	**Lack of Proper Storage**	**Not Using a Storage Matrix**	**Explosion**
		Failure to Provide Sealing	
2	**Not Using Appropriate Equipment/Installations**	**Not Using Exproof Equipment/Installations**	**Fire**
3	**No Lightning Rod in the Storage Area**	**Lightning Rod Does Not Cover the Warehouse Section**	**Explosion**
4	**Not taking protective measures on shelves**	**Ground**	**Don't cause an explosion**
		Risk of rollover	**injury**

5. Discussion and Conclusion

As a result of the analysis of the workflow process in the polyester resin production facility using the FRAM method, five main functions were defined and four scenarios were created. In FRAM modeling, the "F5 Storage" function has emerged as the focal point of the processes. Any negative situation or disruption at this point will cause negative situations throughout the facility. Decisions to be taken in the storage of products can ensure the effective and safe operation of the facility. Storing the products in accordance with the correct temperature, humidity and other storage conditions preserves the quality of the products and plays an important role in ensuring the safety of the facility. Appropriate security measures to be taken for warehouse security will reduce hazards and risks throughout the facility.

The "F5 Storage" function affects and is affected by other systems, and therefore interacts with other functions. For this function, these risks will affect the normal operation of other modules in the FRAM. Interactions between Storage, Periodic Control, Reactor, Freight Elevator and Blender may cause the current state of the system to change, as well as increase risk scores and cause accidents to occur.

This work; It was prepared to analyze the potential hazards and risks that may occur in the workflow processes in a polyester resin production facility with the Functional Resonance Analysis Method (FRAM) and to identify the stages that prevent the processes from being optimized and to make recommendations to reduce the relevant risks.

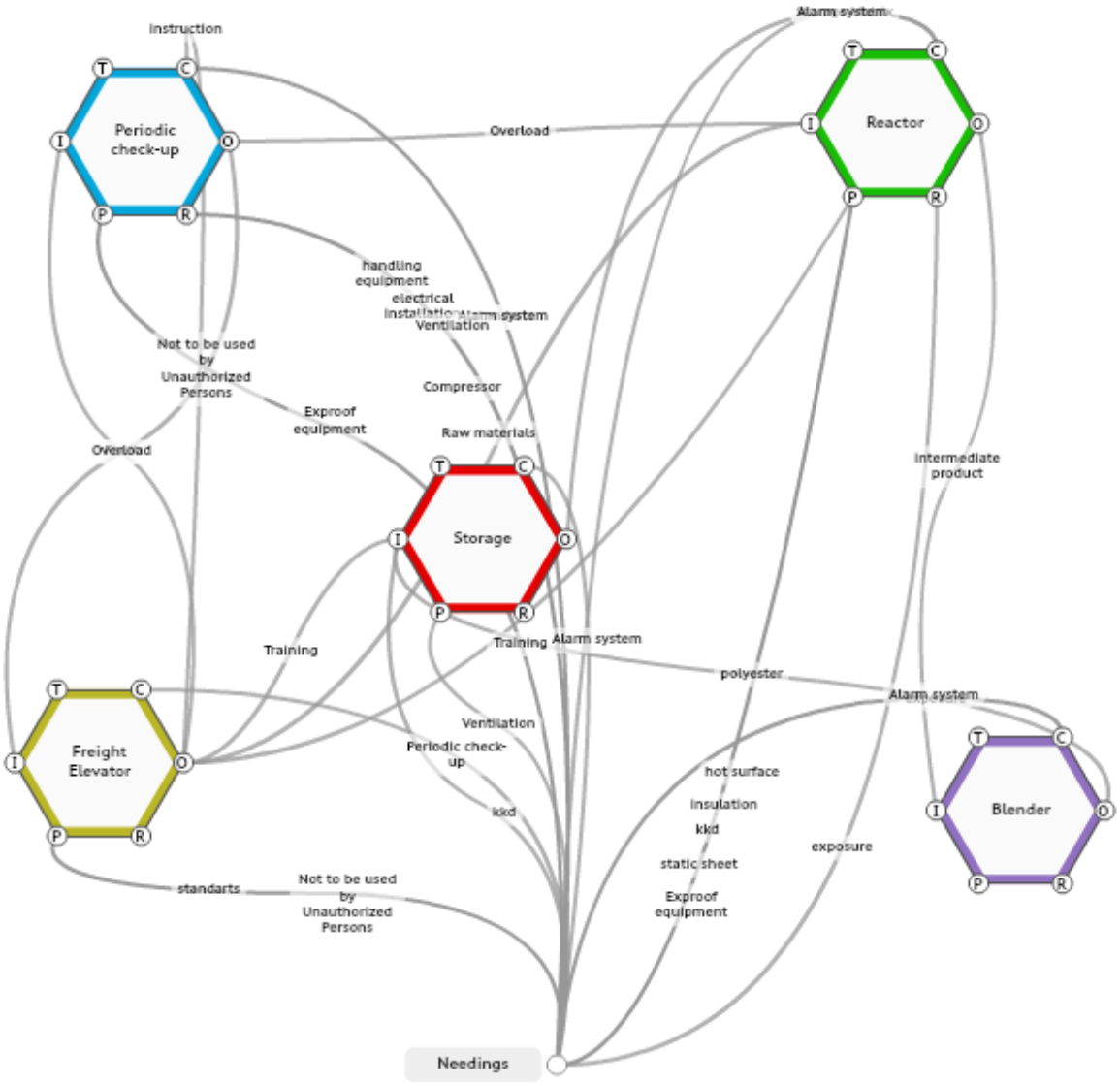

Figure 2. FRAM model of the process in the Production Plant

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Araştırmacıların Katılım Oranları

Conflict of Interest / Çıkar Çatışması

Yazarlar tarafından herhangi bir çıkar çatışması beyan edilmemiştir.