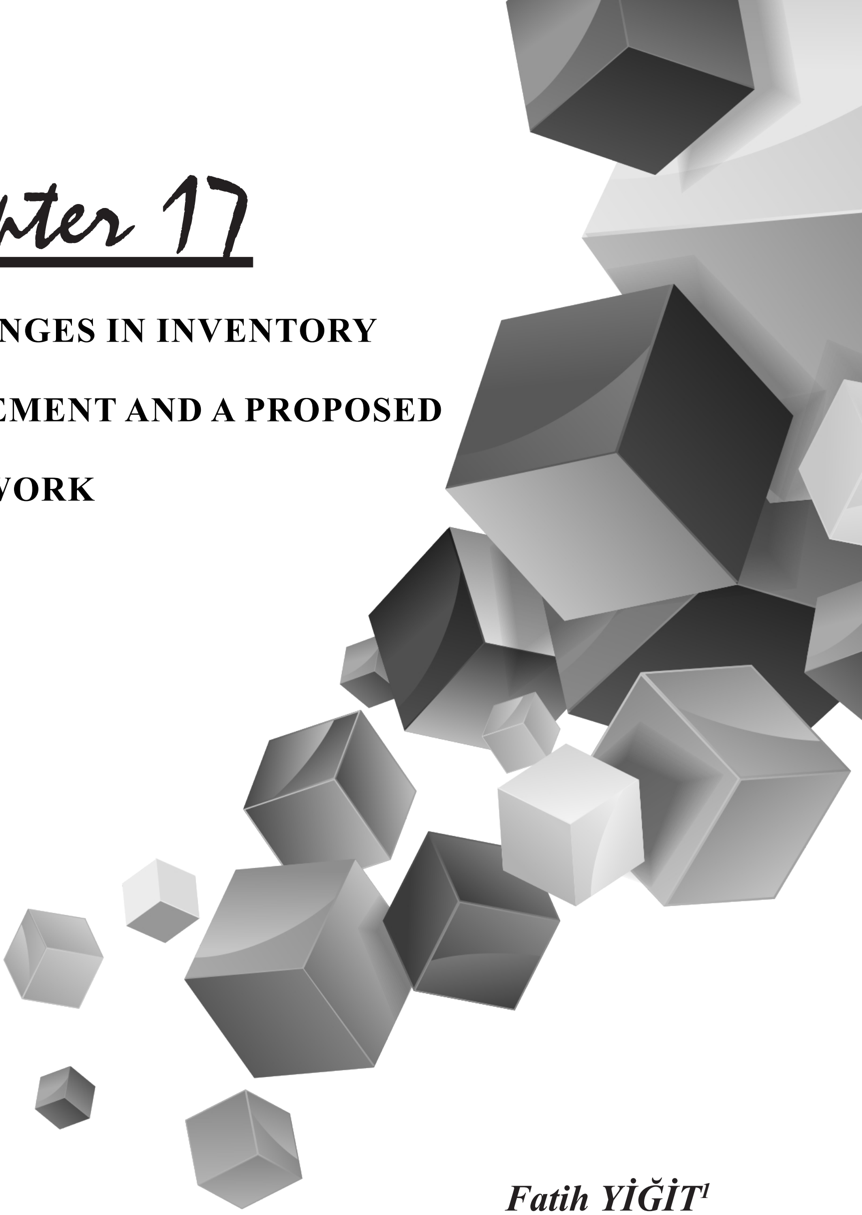

Chapter 17

CHALLENGES IN INVENTORY MANAGEMENT AND A PROPOSED FRAMEWORK

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1 Introduction

In today's economy, efficient inventory management is vital for all companies. Business environment, which is considered as volatile, uncertain, complex, and ambiguous (VUCA), big savings can be achieved with efficient inventory management. Effective implementation and management of inventory management system is vital for a company's success. The success of such implementation not only affects the profit but also customer satisfaction.

Despite the many challenges are faced by practitioners, most of them are not mentioned in textbooks. Proposed framework aims to investigate these challenges by systematic literature review and propose methods to overcome these problems. The intention is to cover the gap between practice and theory.

Inventory management is becoming more complex due to new challenges. To name a few, product life cycles become shorter, demand becomes more unpredictable, green supply chain and relevant new topics adding complexity to the issue.

The increased financial costs put additional pressure on companies. As a result, companies are focusing on net working capital (NWC) to free additional cash. One of the three pillars of NWC is inventory besides account receivables and payables.

Inventory management is complex in nature due to many stakeholders involved with conflicting goals. These goals and stakeholders may change with the type of inventory. Spare parts are critical for a manufacturing site therefore a plant or maintenance manager is involved with this type of inventory. Similarly finished product inventory level is important for a sales manager as it directly affects the customer service level and logistics manager due to warehouse limitations.

Raw material inventory level is associated with the performance of planning manager and supply manager. Increased inventory levels give the planning manager freedom to switch production or compensate any unpredictable incidents. Additional safety stock also helps supply manager to overcome any supply problems. A purchasing manager wishes to increase the inventory in order to get additional discounts from suppliers.

There are also other departments which have contradicting goals. For logistics or warehousing managers, the higher turnover is desirable. This high turnover gives freedom for the warehousing manager to optimize the inventory. For a finance manager, NWC reduction is a primary goal. Therefore, a decrease in inventory is important as it both frees cash that can be used elsewhere such as investments, and due to reduced financial costs.

On the other hand, high inventory level gives the sales team flexibility to compensate forecast variations. Such additional inventory also allows sales department to approach new customers without sacrificing service level of existing customers.

Inventory management should be a joint effort due to the importance and effects on the overall success of a company. Therefore, all members of an institution should have the responsibility of inventory management. This way, a collaboration among members can be achieved. Besides, the most valuable issue is requirement of better quality of the information flow between partners in supply chain, what needs: close relationships, activities coordination, reliable and accurate information (Czwajda and Kosacka 2017).

The framework suggested is about to overcome the focuses on challenges faced by practitioners working in the field of inventory management. Effective inventory management provides a potential system to improve performance by matching inventory management practices and competitive advantages (Mahyadin et al. 2013). The study first makes an overall explanation of challenges and shares the proposed methods to overcome these challenges.

2 Importance of Inventory Management

Supply chain is a vital part of business. With globalization, many companies prefer to supply goods which fits their strategies regardless of locations. Proper management of supply chain has therefore a strong effect of the performance of a company.

Inventory management typically is considered as a part of supply chain management. The importance of proper inventory management lies mainly on two reasons. The first reason is customer service level and the second one is its effect on the total cost of inventory and eventually NWC.

Customer service level is critical due to its effect on customer retention and sales revenue generated. Modern customer service, if it is based on appropriate standards, makes a great impression on customers. Consequently, they are willing to buy goods or services again (Skowron and Cehaba 2019). Therefore, proper management of inventory management directly affects the revenue generated.

Inventory management has also an effect on financials. Cost effect of inventory is a part of inventory models due to costs associated with inventory decisions. These costs are split into inventory and ordering costs. As a result, proper inventory management lowers the total cost of inventory. On the other hand, another aspect of inventory management is its effect on NWC. NWC is the cash tied for the everyday running of a company. Practically is the amount of cash tied to receivables and inventory vs payables.

NWC is a critical financial ratio used for firm valuation and a critical key performance indicator (KPI) for the assessment of proper financial management. A study by PricewaterhouseCoopers (PwC) (2020) shows that days inventory outstanding (DIO) is one of the two major areas for improvement in NWC. The same study shows that typical DIO is 56.2 days in 2018. In some sectors such as pharmaceuticals and life sciences worldwide, the DIO may reach up to 200 days.

These numbers show the reason behind the proposed framework that has the goal of defining a method for effective inventory management.

3 Challenges

Challenge is defined as "(the situation of being faced with) something that needs great mental or physical effort in order to be done successfully and therefore tests a person's ability" (Cambridge Dictionary 2020).

As can be interpreted from the definition, it covers the many issues that practitioners face who work in business life. As a result, challenges faced is an area where academic studies are made. On the other hand, based on our best knowledge and review, an extensive study and proposed solutions are not available in literature.

Most of the studies covers a specific area where a unique challenge is met. To name a few, challenges in demand modeling for slow moving goods is reviewed by Grange (1998). In this study, the specific but usually undervalued items of slow-moving items is investigated. The study underlines the challenges faced for the demand distribution of slow-moving items and proposes alternative methods to predict slow-moving items demand. The outcome of the study proves that misapplication of a demand distribution will yield unsatisfactory inventory optimization results.

Dhoka and Choudary (2013) investigated the demand uncertainty and eventual classification of XYZ to overcome the challenges faced by uncertainty. According to the study there are different reasons that causes uncertainty. Highly critical parts low in consumption value may be overlooked and periodic updates and review become critical and cannot precisely consider all problems of inventory control like thousands of low value items.

Various MRP tools and techniques address both shortcomings by coordinating the quantities and timing of the deliveries from known target requirement to minimize cost or achieve desired service levels (Stößlein et al. 2013). With realistic lead times and realistic forecasts, the resulting inventories would be optimal for the circumstances. Lack of realism in the areas, however, undermined the operation of MRP systems, yielding less than the desired service and more than desired inventories (Dhoka and Choudary 2013). Also, as periods of planning horizon increases the forecasting errors are affected adversely (Beutel and Minner 2012).

Similarly, perishable products' inventory management is complex in nature and deserves specific focus. Based on extensive research no specific attention is given to the effects of inventory management decisions for perishable products. Typical safety stock calculation neglects the perishability of products. Also, classical methods such as economical-order-quantity (EOQ) doesn't cover the mentioned effects on perishable products. Therefore, perishable products are considered as an additional challenge for practitioners.

New regulations associated with environmental concerns also causes additional challenges for production and inventory managers. Study by Inman (1999) shows that environmental management trends have profound effect on production and inventory managers. Although some methods has been proposed to cope with some of the problems, there are still some others that have no solution. Such challenges can only be solved with proper training and skills. With proper skill and training, the practitioners can adapt to changing needs.

Globalization, shorter product life cycle, rapidly changing demand and increase in the expectations and demands of customers, confirm that world is changing dynamically, what affects increasing requirements for supply chain (Czwajda and Kosacka 2017).

Therefore, skills and trainings are major areas for improvement in inventory management.

Such challenges are not prevalent in only manufacturing industry but also in some other areas such as service. A study by Boone et al. (2008), investigates the critical issues faced by service parts managers and help to gap the bridge between theory and practice.

A study made by Patil and Divekar (2014), investigates the inventory management challenges of B2C E-Commerce retailers. Although the study is sector specific, the outcomes covers the challenges in demand variations, reverse logistics, seasonal fluctuations, and stockless policy. The risks involved associated with underperforming inventory management are lost sales, lost customers, low customer satisfaction. To counter these challenges online retailers adopted strategies such as dropship strategy, classification of inventory, hybrid strategy, pre-purchase stocks and stock less policy that is purchasing stocks after customer orders.

Some the challenges are more specific in nature. In return, more specific studies are made in literature.

A study by Czwajda and Kosacka (2017) investigates the challenges due to multi-echelon inventory management. According to the study, a multi-echelon inventory is more complex in nature compared to single-echelon inventory. The study contributes, the introduction of challenges of multi-level inventory systems. The study shows that multi-echelon systems makes the inventory management more complex compared to single-echelon systems.

With increased level of inventory management, there is an increased level of uncertainty and complexity in inventory management. As a result, additional challenges are prevalent in such environment.

Practitioners face some issues that are not solved by inventory models or such theoretical knowledge in textbooks. Classical models incorporate, deterministic and probabilistic inventory models, with quantity discounts, MRP applications, replenishment policies or such. In literature, inventory management textbook covers the EOQ that aims to minimize the total cost but ignores the additional cost of perishability, waste of stock etc. Besides many constraints prevalent in business life are not adequately presented such as budget, total quantity procured, limitation from one or more type of products procured or stored etc.

Research Gap = What is clear from the foregoing literature, there are many studies existing regarding "inventory models" and proposed methodologies. On the other hand, as far as we investigated, there aren't any studies regarding the challenges faced for inventory management practitioners. Thus, the main objective of this study is;

- To identify the challenges
- To identify the reasons
- To identify the proposals for solutions
- To create a decision support infrastructure to be used for inventory management

As a result, the primary purpose of this chapter is to cover the gap between practice and theory. This can further be achieved by application of artificial intelligence and/or fuzzy systems. In the following subsection, each challenge is given.

3.1 Multi- Echelon

The concept of multi-echelon inventory management has gained importance over the last decade mainly because of increasing complexity of supply chain and dynamic development of information technology what enables integrated control of supply chains consisting of several processing and distribution stages. (Gumus and Guneri 2009) The multi-echelon systems made the already complex inventory management more complex.

Although multi-echelon inventory has many benefits such as shorter replenishment times, proximity to point of consumption, higher customer service level. Low performance in management may cause increased stock due to bull-whip effect, higher waste and scrap due to perishability, increased dead and slow movers due to storage in different locations, increased costs due to increased logistics costs partly because of less-than-truckload (LTL) shipments.

The bullwhip effect refers to increasing swings in inventory in supply chain in response to ineffective information flow, what results in excessive accumulation of stocks in particular supply chain partners. It is also called "misalignment between the demand and order signal" (Costantino et al. 2015a). Inadequate information flow or lack of them between the partners in the supply chain, leads to distortion of information moving along the supply chain. It results in the intensification of demand variability and the bullwhip effect (Lee 2003).

This phenomenon creates serious problems partners in the supply chain, causing errors in demand forecasts, low capacity utilization, excess inventory, and poor customer service.

Study by Costantino et al. (2015b) showed the importance of bull-whip effect on supply chain and in particular inventory management decisions. Also indicated that many studies in literature don't propose solutions that are easy to implement and acceptable when cost-benefit comparison is made. The proposed framework aims to fill this gap by evaluating an ordering policy that can mitigate the bullwhip effect while keeping acceptable inventory performance. The proposed actions to counter this gap is given in Section 4.1.

3.2 Visibility of inventories

Visibility of the inventories is a critical factor for inventory management. Any deviation may cause a deviation between intended target and outcome.

Typically, accuracy of the inventory may change from sector to sector because of the uniqueness of the products and environment. The deviations don't occur only because of the typical losses such as wrong shipments, losses or theft but also due to the nature of the products. Chemicals and food products has a tendency to expire with the limited shelf-life. After the shelf-life the products lose their value significantly or become waste.

Also, a study made by Raman et al. (2001) inaccurate inventory records has reduced profits by ten percent.

Therefore, accuracy of the inventory records is vital for the performance of an inventory management system and necessary actions should be taken accordingly.

3.3 Uncertainty

Uncertainty is an important risk in inventory management. Uncertainty may arise from internal factors or external factors. Lack of accurate data for demand, inventory, costs, lead times, inventory records may undermine the performance of any decision made. These factors are considered as internal factors. Economical or global instability that affects the demand, or new regulations may affect the business.

Davis (1993) pointed out that, the key issue affecting the efficiency of the supply chain is uncertainty. The reason of keeping safety stock is mainly to deal with uncertainty in supply chain. According to Czwajda and Kosacka (2017), globalization, technological change, increasing demands from customer for better service lead to increased requirements from supply chain. In return it may result in a higher level of uncertainty for the organization and thus a higher level of incurred risk.

Consequently, it impedes achieving their objectives (Pluta-Zaremba 2008). Proper risk management and effective collaboration among all responsible parties would help to overcome the negative effects.

In order to counter the disadvantages of uncertainty, proposed measures are given in section 4.3.

3.4 Skills and Training

Lack of skills and proper training of the professionals can be a major issue for the efficiency of inventory management. Most of the necessary skills can be acquired with formal undergraduate or graduate level educations, also specific courses can be taken to acquire required skills when necessary. The main understanding of inventory management principles and methods are vital for an effective management.

The factors, documentation/store records, planning, knowledge of employees/staff skill have shown to significantly influence the effectiveness of inventory management while the funds have shown slightly significant influence on the inventory management in manufacturing small medium enterprises (Chan et al. 2017).

Study conducted by Mahyadin et al. (2013) in the area of inventory management practices revealed that improper management may have been caused by the level of skills that the practitioners have. Although experience in a specific area is important, it may also cause some important areas for improvement to be overlooked.

In section 4.4, a framework for the assessment and training subjects or skills of a practitioner is given accordingly. In return, the suggested framework will provide a guidance to cover a possible gap in this area.

3.5 Product Classification (ABC Analysis)

There are also challenges faced due to product specific characteristics. Some typical characteristics are, short expiry periods, dangerous or extremely valuable goods and substitute products. Generalization of such products may cause their importance or need for special management to be ignored. Some products may be extremely important for production or for a customer. Such classification may cause products to be classified under the lowest class of C. Therefore, the desired customer service level cause them regularly to be out-of-stock and cause the performance of inventory management system to underperform. In Section 4.5, some specific attributes of products are given. By assessing products accordingly or managing products based on these specifications may contribute the performance of the total inventory system.

3.6 Perishability

Products with shelf-life are not taken into consideration by main textbooks in the area of inventory management.

Typical safety stock calculation and economical order quantity (EOQ) models ignore the perishability attribute of products. Therefore, if all other values such as lead time, lead time variability, ordering and stock keeping costs and variability of these values are same, the outcome will be the same for a perishable or non-perishable product.

Although there are research in this area, they may be too complicated for either practitioners or case specific. To overcome these problems, applications implementing proposed models can be used for inventory management decisions.

In literature, there are studies associated with the perishable products, most may be considered too complicated for daily use. The mathematical model proposed in Section 4.6 takes into consideration the perishability of products. of the total cost. perishability of products. The goal is to integrate this attribute into the proposed model with the objective of achieving minimization of cost and satisfying constraints such as budget, total inventory level etc.

3.7 Type of inventories, different strategies.

Especially when the number of products increase, it is important to classify, products based on their importance. Therefore, ABC analysis is a widely used approach for the classification of goods. After 70 years, the need for more complex classifications emerged. Single criterion classification is not enough to assess the importance of inventory and make decisions accordingly. As a result, multiple criteria approaches are realized and implemented. This subsection of inventory classification is called multiple criteria inventory classification (MCIC). Although such application is better to define the inputs for business decisions, such applications also bring additional workload and complexity. To make accurate assessments, relevant criteria should be agreed among the decision makers. Besides decisions about criteria, classification methods should be accurately decided.

Although inventory classification models such as ABC analysis models are used for classifications, some items in inventory are not accurately defined in such classifications. Therefore, some other goods should be classified based on different characteristics. A typical class for such classification is slow moving items and dead items.

The distinction between slow moving items typically has low demand but due to goods in inventory, it may have a significant effect on a company's financials along with dead stock. According to Sugumaran and Sukumaran (2019) dead stock is a major issue in garment industry as it affects business cash flow, takes up valuable warehouse space and freezes earnings that otherwise should be dedicated to the purchase of revenue-generating products. Unsold garments that remain in warehouses, see zero sales in a defined number of months, and retard business growth, can be referred to as "dead stock".

Challenges are about the definition of slow-moving items and definition of goods with very minimal demand close to "0". Such products are called "dead stock" in literature. A definition of slow-movers and dead-stock is given in Section 4.7. Such classificiation and exceptions may be revised based on the specific cases of the practitioners.

In the same section, necessary actions to lower the amount of dead-stock and slow-moving items is given as well.

3.8 General Inventory Models

In typical inventory models namely deterministic or stochastic models, constraints are not considered. In economic order quantity models, based on the demand and costs an optimum quantity is calculated to lower the total cost. On the other hand, such application does not take into consideration the constraints faced in business life.

Typical objective is the total inventory cost which are limited with the budget or financial availability, expiry dates and perishability, special concerns associated with product specific requirements such as food grade, dangerous goods etc. However, in business life, most of the decisions are subject to some constraints. Such constraints can be physical, financial, environmental or such. Warehousing capacity, outsourced warehouse capacity, total value of purchase or inventory value, total amount of inventory or purchase are some examples of such constraints.

In typical textbook models, inventory models don't cover the price fluctuations of goods and/or perishability of products. In deterministic or stochastic models' emphasis is given for safety stocks and economical order quantities. In these models' prices are considered as fixed and products have no shelf-life. As a result, all inventory decisions will be same for products regardless of their shelf-life.

The proposed model in Section 4.6, aims to cover the gap in literature. The proposed model covers not only the total cost structure but also the constraints that are a part of the any inventory decision. When integrated into a software system, applications will fit more to the realities of business life.

4 Model Formulation and Proposed Framework

In Section 4, the details of the approach proposed is given. Methodology of the study consists of exploratory survey of relevant literature and analysis of the experience of the author based on 15+ years of experience in inventory management. Typical measures to overcome each challenge group are discussed separately in the remaining of the section 4.

4.1 Multi-Echelon Systems Management

Due to customer service requirements or logistics networks, multi-echelon inventory systems are widely used in business. A typical comparison between single and multi-echelon distribution systems is given in Fig.1.

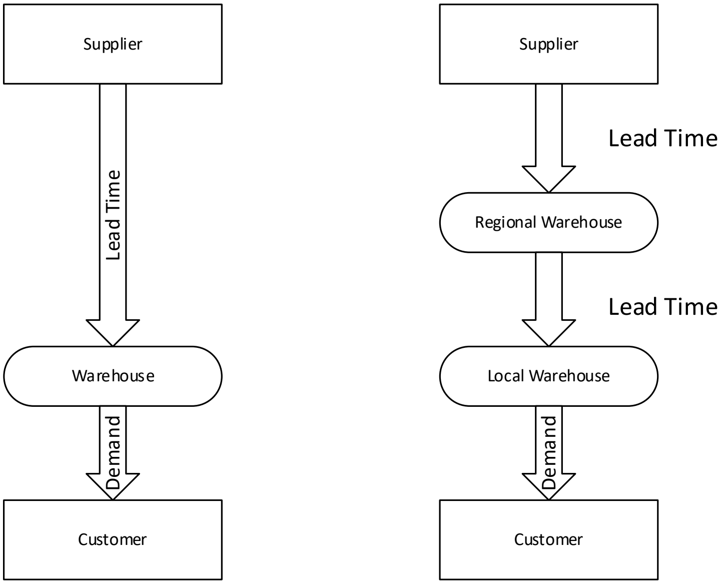


Figure 1 Single and Multi-Echelon Systems

Multi-echelon inventory systems cause bull-whip effects. Bullwhip effect represents the amplification and distortion of demand variability as moving upstream in a supply chain, causing excessive inventories, insufficient capacities, and high operational costs. Bull-whip effect is a typical problem for inventory systems, as additional layers causes complexity and vagueness in inventory systems. Study by Zhu et al. (2020) shows that, multi echelon system can create significant inefficiencies in the supply chain (e.g., excessive inventories, misguided production or capacity planning, poor customer service and lost revenue due to shortages).

A growing body of literature recognizes ordering policies and the lack of coordination as two main causes of the bullwhip effect, suggesting different techniques of intervention (Costantino et al. 2015a).

Excessive inventories and reduced customer service level due to stock outs may undermine the performance of inventory systems. The integration of traditional ordering policies with a collaborative approach proved its success in different configurations as for Information-Enriched Supply Chain, Vendor Managed Inventory, Quick Response and Collaborative Planning, Forecasting and Replenishment (CPFR) (Costantino et al. 2015a).

Therefore, the proposed framework will cover a forecasting system implementation that will be regularly checked about the discrepancies and modified accordingly. Besides, such forecasting system every part of the organization should have the responsibility of such implementation and execution.

The forecast phase in the framework given in Section 5 covers two alternative forecasting techniques and a feedback from relevant departments. The mentioned workflow of the framework also covers the assessment of the accuracy to find the reasons of deviations and to take necessary actions.

4.2 Inventory Visibility

Visibility of inventory is a major concern. In order to make accurate decisions, any decision maker needs the status of inventories. Typical models cover the lead time and/or demand as probabilistic and quantities on hand as deterministic. Unfortunately, due to frequent wastes, wrong shipments, theft etc. it is not always possible to have the accurate figures in the system compared to the actual inventory on hand.

As a result, inventory records in the system may deviate from the actual values that are used for decisions. Therefore, physical inventory procedures should be executed not only due to accounting requirements but also for to ensure that the actual and records are accurate.

The first action is to implement a strategy to make physical inventory procedures, a method to overcome discrepancies. Physical inventory routine should be used both for accuracy and for improving the inventory status. Each physical inventory procedure should be accompanied by meetings with the goal of improvement of the inventory record keeping. Also, physical inventory periods should be relevant with the accuracy. As an example, the physical inventory should be done monthly till the discrepancy is above %3 and so.

Additionally, whenever possible inventory records should be done based on actual values and recorded at the time of consumption or receipt. Address assignment to each lot or use of technologies such as RFID or barcoding systems would contribute the performance of inventory management.

The workflow will cover the actions necessary to assess the situation and take necessary actions to improve the accuracy and hence the visibility of inventory.

4.3 Uncertainty

A factor of uncertainty does not only affect the inventory but also other functions of an organization. Modern applications such as grey systems is used to overcome such problems. In order to overcome this issue in the area of inventory management, safety stock is used.

The sources of uncertainty can be divided into three groups (Simangunsong et al. 2012):

1. Uncertainties from the focal company, e.g. internal organization uncertainty (product characteristics, manufacturing process, control/chaos, decision complexity, organizational/behavioral issues and IT/IS complexity)

2. Internal uncertainty of the supply-chain arising within the realm of control of the focal company or its supply chain partners (end-customer demand, demand amplification, supplier, parallel interaction, order forecast horizon and chain configuration, infrastructure and facilities)

3. External uncertainties, associated with factors outside the supply chain, which are outside a company's direct areas of control (environment, government regulation, competitor behavior and macroeconomic issues, and disasters)

Considering uncertainty will be a part of any business decisions necessary actions should be taken to counter uncertainty. To deal with uncertainty, the data that is used for decision making should be as accurate as possible. By the application of ABC analysis, more focus can be applied on the A class that has a higher effect on the outcomes. Therefore, the proposed framework given in Section 5 will integrate and ABC analysis and use of a traditional safety stock calculation with the goal of achieving customer service level.

4.4 Skills and Training

As stated in chapter 3., skills of inventory management professionals directly affect the performance of the desired system. Typical educational programs aim to improve the educational level of professionals. The proposed model includes the assessment of the training need of the relevant staff in some areas, which are mandatory for professionals. As stated in Chapter 6, the suggested workflow covers the assessment of the skills of the responsible people. After the assessment, proper trainings should be conducted to cover the gap between the desired level and status. Adequately trained practitioners are a key factor for the efficient management of the proposed framework.

A typical inventory management responsible should be well trained in the following areas.

- MRP & DRP Systems
- Economical Order Quantities (EOQ)
- Inventory Models & Inventory Related Costs
- ABC Classification
- Physical Inventory Procedures

- Safety Stocks & Customer Service Level
- Forecasting
- Spreadsheet Experience and Expertise
- Basic Statistics

The proposed model and framework cover the assessment of necessary skills and relevant trainings as well. Accurate assessment of the skills of the inventory management practitioners is although beyond this study, an experienced manager may evaluate the current levels of practitioners with high accuracy.

4.5 Management of Extreme Cases

Generalization of all products to limited classes via ABC analysis may cause products that need special attention to be neglected. Therefore, after the classification of goods, some exceptions may be needed. The proper management of exceptions involves defining some special categories. These categories are managed according to different specifications and needs. To name a few, a product that can only be used with a different material e.g two component glue, or a product that is subject to strict regulations in terms of storage or sales, explosives, or toxic materials. These exceptions should be managed according to specific needs.

The workflow proposed in Chapter 5, covers the typical sub specifications that can't be addressed under ABC classification.

Such classifications are;

- Complementary items
- High perishability items
- Items with extremely high value/quantity ratio
- Products subject to product specific regulations (e.g. food, feed etc.)
- Dangerous Goods (Toxic, Flammable, Oxidizers etc.)

4.6 Management of Perishable Products

Typical inventory policies or models do not make any distinction between perishable or non-perishable products. As a result, proper management of perishable goods is mandatory for the effective management of goods. Our proposed model takes into consideration of goods that has a shelf-life and costs associated with these goods. In the last phase of the model, where the objective function is defined to cover the perishability of products.

Lack of policies that covers the overall global strategy causes significant local decisions to be made. Such decisions are optimal from limited perspective. Such decisions cause local gains and profits from that view but on the other side may generate greater losses.

The behavior of a purchasing agent may be given as an example. In case of a huge price discount, due to lower costs, a typical behavior would be to give orders covering the many months ahead. Alternatively, especially in container shipments, the minimum ordering quantity is considered as the quantity in a container. Whereas accepting some dead freight, total quantity may be negotiable with the supplier. Therefore, to cover the gap between local and global optimum decisions, policies covering inventory decisions should be clearly defined. Such policies are purchasing, warehousing and inventory related investments such as packaging, new warehousing investments etc.

In the proposed framework costs such as deterioration, damage and wear are included in the cost of inventory. If a product remains in stock beyond its expiration date, the product becomes unusable and there is a loss equal to the value of the product. On the other hand, this spoiled product must be disposed of in accordance with the laws. The disposal costs incurred as a result of this process should also be added to the total cost.

In order for a product to become waste or obsolete, the product purchased in a certain period must not be sold within the expiration period. Stocks on hand must be used or sold according to First-In-First-Out (FIFO) principle. Therefore, the demands within the expiry period must first be deducted from the existing stock, and the remaining demand must be deducted from the amount that will come from the newly arrived product.

It is important that the new product is consumed within the expiration period to avoid deterioration, aging and related disposal costs.

The equation for deterioration and aging costs is given in Eq. 5.1. In the said equation, it is formulated that if a product does not receive enough demand within the expiration period, after the product is supplied, the quantity in stock will expire and the associated costs will occur.

$$BY_{xt} = \begin{cases} t < k = 0 \\ t > k = HaMx(t-k) - \sum_{t=t-k}^{n} Tlpxt \end{cases}$$

$$TWC = \sum_{x=1}^{m} \sum_{t=1}^{n} (BY_{xt} * (BuM_{xt} + UC_{x}) \qquad \forall x, t$$

$$PI_{xt} = PI_x(t-1) - HaM_{xt} + Tlp_{xt} - BY_{xt} \tag{5.1}$$

$$SC_{xt} = PI_{xt} * (UC_x + WC_x + FC_{xt})$$

$$TSC = \sum_{t=1}^{n} \sum_{x=1}^{m} SC_{xt} \quad \forall x, t$$

$$OC_{xt} = \begin{cases} OC_{xt} & if\ HaM_{xt} > 0 \\ 0 & if\ HaM_{xt} < 0 \end{cases}$$

$$TOC = \sum_{t=1}^{n} \sum_{x=1}^{m} OC_{xt} \quad \forall x, t$$

The following constraints should be taken into consideration.

Customer Service Level

$$CS_x = \frac{PI_{xt}}{Tlp_{xt}} \quad \forall x, t$$

Total Purchased Quantity

$$\sum_{x=1}^{m} \sum_{t=1}^{n} HaM_{xt} \leq TP$$

Total Purchased Value

$$\sum_{x=1}^{m} \sum_{t=1}^{n} HaM_{xt} * UC_x \leq TPV$$

Total Waste

$$\sum_{x=1}^{m} \sum_{t=1}^{n} HaM_{xt} * UC_x \leq TPV$$

Total Amount of Procured from Product

$$\sum_{t=1}^{n} HaM_{xt} \leq TAP_x$$

x = Product number (x = 1, 2, 3,….m)

t = Period (t = 1, 2, 3, ….n)

k_x = Expiry period for product x

PI_{xt} = Inventory on hand per period t per product x

HaM_{xt} = Calculated Order Quantity per period t per product x

Tlp_{xt} = Demand per period t per product x

CS_x = Customer Service Level for the product x

TP = Total Purchased Quantity Constraint Value

TPV Total Purchased Value Constraint Value

TWL = Total Waste Quantity Constraint Value

TAP_x = Total Procured Quantity Constraint Value for the product x

BY_{xt} = Perished product quantity per period t per product x

BU_{xt} = Waste cost per period t per product x

UC_x = Unit cost per product x

WC_x = Warehousing cost per product x

FC_{xt} = Financial cost per period t per product x

SC_x = Storage cost per period t per product x

OC_{xt} = Ordering cost per period t per product x

TWC = Total Waste Cost

TSC = Total Storage Cost

TOC = Total Ordering Cost

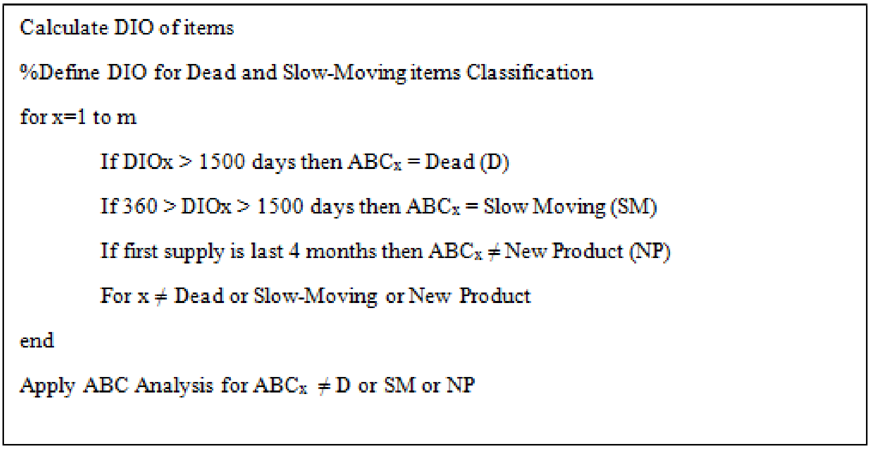
4.7 Inventory Classification

A typical method to classify goods according to their consumption is to use the inventory turnover or days in inventory (DIO) metrics. As mentioned in chapter 3.7, such methodology is limited. Based on characteristics given is Section 3.7, products need to be classified based on not only value or turnover but also more elaborative approaches. In literature such classifications are given in multi criteria inventory classification (MCIC). In the proposed methodology, a MCIC model proposed by Yiğit and Esnaf (2020) is used for such classification. Dead and slow-moving items are not classified under such model. To solve this problem, assessment of dead and slow mover is executed before MCIC model application. To classify dead and slow-moving items following workflow is used.

As an example, classifying goods with “0” or very low demand as dead stocks, can also classify the newly supplied goods as well. Regular new purchases with new SKU’s makes the classification difficult. Especially in sectors with high turnover such as fast fashion low priced alternatives make the traditional use of turnover or days inventory outstanding (DIO) classification of slow-movers or dead stocks difficult.

In the study prepared by Grange (1998) of all dealer's parts that is, these with 20 or more weeks of very low or zero demand in a year. On the other hand, classifying good based on their consumptions is sometimes difficult.

In the flowchart given below, DIO of 1500 days is used for Dead items, DIO between 360 and 1500 days is used for Slow Moving goods. 4 month no consumption is used for defining new products.



```
Calculate DIO of items
%Define DIO for Dead and Slow-Moving items Classification
for x=1 to m
        If DIOx > 1500 days then $ABC_x$ = Dead (D)
        If 360 > DIOx > 1500 days then $ABC_x$ = Slow Moving (SM)
        If first supply is last 4 months then $ABC_x \neq$ New Product (NP)
        For x ≠ Dead or Slow-Moving or New Product
end
Apply ABC Analysis for $ABC_x \neq$ D or SM or NP
```

Figure 2 Dead-Slow Moving or New Product Classification Algorithm

Therefore, the variables may be amended based on changing needs of the practitioner. In the algorithm given below, 4 months is considered as time needed for new products. 4 months can be as less as 1-2 days for new products in retail business or 4 months in chemical business.

4.8 Forecasting

Inventory models proposed in literature do not cover some of the challenges faced by inventory management practitioners.

Forecasting of future demand is an important area for inventory management practitioners. Typical textbook inventory models cover future demand as a probabilistic demand or forecast is covered entirely another area for research. The proposed model covers the forecasting procedure as a part of inventory management decisions. Therefore, when not enough data is available for future decisions, forecasting procedure will help the decision maker for such decisions.

The proposed framework aims to help practitioners to apply a workflow to gain benefits in inventory management. The proposed framework covers a selection of alternatives among alternatives or use of hybrid methodology for an efficient forecasting system. As given in Figure

3, sales department should be a part of forecasting methodology. Also, relevant feedbacks should be given to parties based on the performance feedback of forecasts.

5 Proposed Methodology for Inventory Management

The flowchart given in Figure 3 represents a workflow that covers the proposed methodology for an efficient inventory management.

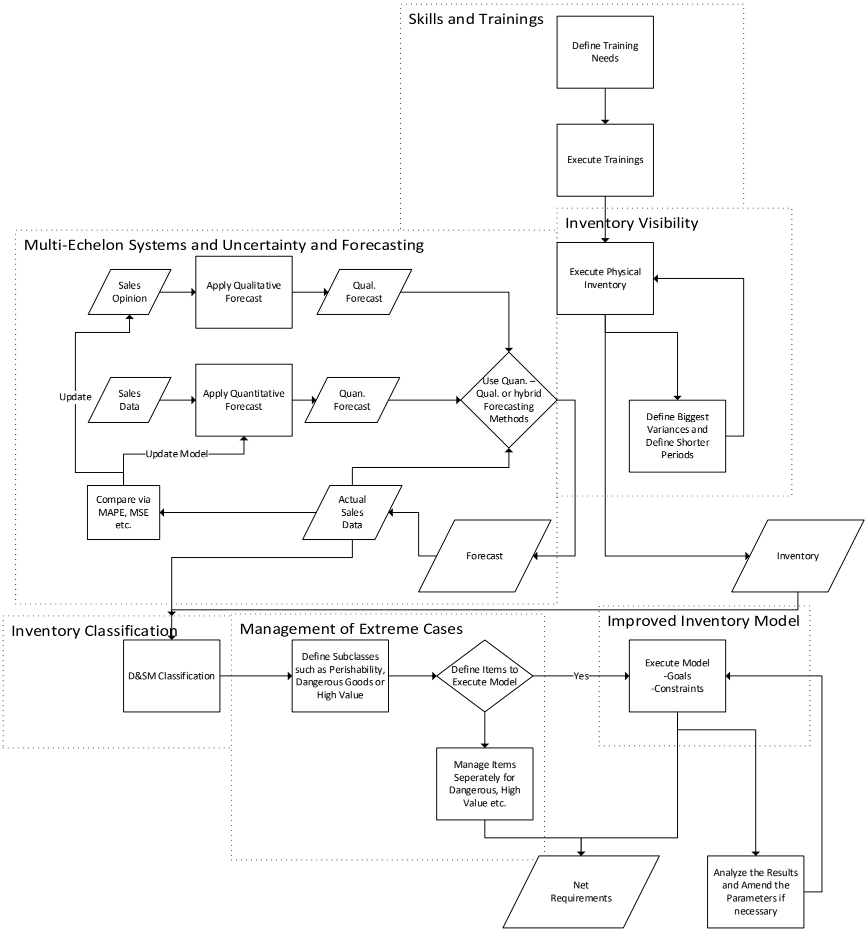


Figure 3Flowchart of the Proposed Framework

6 Conclusion

Inventory practitioners face many challenges, especially in the early stages of learning curve. Normally, inventory management involves decisions based on vague information such as sales demand, lead times and sound information such as inventory level. However, actions such as use of forecasting is as good as the application. Also, information that is expected to be sound is sometimes not enough accurate. Therefore, the proposed framework covers the forecasting phase to solve this issue. Also a skills and training phase is added in order to assess the level of the training of decision-makers to take necessary actions. D&SM and extreme cases identification along with ABC analysis is integrated into the proposed framework to differentiate products. This method allows the decisions maker to focus on the few that has the most value for a business unit. Improved inventory model is given to model a decision that covers both important objectives and constraints. The improved model would help the decision maker to make decision that has the minimum total cost while satisfying the constraints.

Further needs and research in the area may be added to the framework by users who has experience and/or academic background for further improvements.

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1. INTRODUCTION

Concrete is one of the most important materials in civil engineering (Vejmelková et al., 2015). It has been used for long years in water structures, roads, dams, bridges and infrastructure work (Pawan et al., 2015). The mineral additives in roller compacted concrete, self-compacting concretes and lightweight concretes are replaced with cement for meliorate the resistance and durability properties of concrete (Mardani-Aghabaglou et al., 2014). The most prevalent additives used in concrete are silica fume, fly ash, slag. Silica fume is known to increase compressive strength, adherence resistance and durability properties of concrete (Lilkov et al. 2014). Silica fume is the byproduct of silicone and ferro-silicone industry. By heating silicone up to 2000 °C, high purity SiO_2 vapors are produced. The content of silica fume depends on the produced alloy (Siddique, 2014).

When a reinforced concrete structure is exposed to freezing, the water within the capillary pores converts to ice and its volume approximately increases by 9% (Chung et al., 2010). In cold climates, the freeze-thaw phenomenon is one of the most important problems in concrete (Molero et al., 2012). The articles have been conducted regarding the resistance of silica fume containing concrete against freeze-thaw. Chung et. al (2010) investigated the effect of freeze-thaw of concrete containing silica fume and fly ash. Silica fume containing concrete samples performed high durability factor and low chlorine ion permeability (Sun et al., 1999). Sabir (1997) examined the effect of freeze-thaw on concrete with silica fume. At the end of his research, he obtained durability factor for control concrete as 92%, while this result was 85% for silica fume containing concrete. Yazıcı (2008) examined the freeze-thaw resistance of concretes with high amount of fly ash and silica fume. At the end of the study, the compressive strengths of concretes containing silica fume and fly ash were higher than compressive strength of control concrete. Zhang and Li (2013) examined the effects of polypropylene fiber on concrete with silica fume and fly ash subjected to freeze-thaw. When freeze-thaw capacities of concrete were compared which does not contain fiber and concrete containing fiber with silica fume, it was determined that freeze-thaw resistance of concretes containing fiber was higher. It was also reported in the literature that silica fume usage increases the drying shrinkage and tension cracks of concrete (Haque, 1996; Bissonnette, 1995; Rao, 1998; Li et al. 1999).

P-N bonded compounds are formed from the reactions of phosphorus compounds and nitrogenous nucleophiles. The compounds containing double bonds between phosphorus (P) and nitrogen (N) are named as phosphazens. Phosphazenes have organic character as they are dissolved in organic solvents but they also have inorganic character due to P=N chain. Phosphazens, depending on the repetition quantity of $-N=PX_2-$ group in their structure, constitute the biggest class of inorganic macromolecules including many compounds varying from small compounds to polymers (Allcock, 1972). The physical and chemical properties of the phosphazene compounds change depending on the group which is bound to the phosphazene main structure. Therefore, the area of usage is wide. According to the data obtained from the literature, some of the application fields are: dielectric property (Koran et al. 2014), gas sensor (Gleria and Jaeger, 2004) and catalyst support material (Song et al., 2005). They are also used in the medical field as well. In some studies performed on animals, it was observed that they demonstrated tumor formation preventive effect (Song et al., 2005). It was also found out that phosphazene derivatives are effective against bacteria and microorganisms causing various illnesses (Tumer et al., 2013; Akbas et al., 2013). It was observed that organo-phosphazenes have anti-microbial effect (Yilmaz et al., 2002; Koran et al., 2013). Some of the phosphazene derivatives are used as the tooth filling material (Gleria and Jaeger, 2004).

Polymer impregnated concrete is produced by impregnating polymer to concrete. Monomer, which penetrates to thinnest capillary gaps of concrete, is polymerized there and therefore impermeable and high-strength concretes are obtained (Piskin, 2010). As a result of reinforcing concrete with polymer, the strength of concrete increases significantly (Monteny et al., 2001;Puy and Dikeou, 1973). Furthermore, the durability resistance of concrete increases because of the reinforcing of polymer to concrete (Allan and Horn, 2006; Yang et al., 2009; Moreira et al., 2006; Chmielewska, 2007; Ogawa et al., 2007; Shirai, 2007; Cheng, 2006).

In this study, the mechanical properties of concrete subjected to freeze-thaw were modelled by the Taguchi based multiple regression.

2. EXPERIMENTAL MATERIALS AND PROCEDURES

2.1. Materials

The cement (CEM I 42.5 R) used in the experiments was provided from the Cement Factory in Elazig. The super plasticizer was used in mixtures. In the experiments, the silica fume at a rate of 0 %, 10 % and 20 % of the cement was used by weight. The properties of the silica fume and cement were provided in Table 1.

Table 1. *The chemical compositions of silica fume and cement*

Chemical compositions	**Cement**	**Silica fume**
CaO, (%)	62.94	0.71
Al_2O_3, (%)	5.62	0.58
SiO_2, (%)	21.12	91
Fe_2O_3 (%)	3.24	0.24
SO_3, (%)	2.30	1.06

MgO, (%)	2.73	0.33
K_2O, (%)	-	4.34
Na_2O, (%)	-	0.38
Cl, (%)	-	0.8-1.0
Specific gravity (g/cm^3)	3.1	2.2
Specific surface area (cm^2/g)	3430	144000

2.2. Design of Tests

Taguchi method was developed Dr. Taguchi (Davim, 2001). The mechanical properties of concrete generally depend on the physical and chemical additives, curing and durability attacks. In the current study, the ultrasonic pulse velocity and compressive strength of concretes strengthened with polymer including phosphazene subjected to the freeze–thaw cycles and their optimum parameters were found with Taguchi analysis. Moreover, it was developed Taguchi based multiple regression model. The experimental variables were used as the percentage of silica fume used in concrete, the percentage of phosphazene in polymer and curing days. According to these variables, L_9 (3^3) orthogonal test plan was selected in this study. Table 2 shown the level of variables used in the experimental study. In Table 2, the phosphazene in polymer, silica fume and curing days was selected three levels. Then, the mixtures in given Table 3 were prepared. According to these mixtures, the 100×100×100 mm cubes were produced. They removed the molds after keeping for 1 day and were cured at 20±2°C for 3, 7 and 28 days.

Table 2. *The variables used in the experimental study*

	Level 1	**Level 2**	**Level 3**
The percentage of phosphazene in polymer, P (%)	0	1	2
The percentage of silica fume, S (%)	0	5	10
Curing time, T (day)	3	7	28

Table 3. *The mixture proportions*

	Cement (kg/m^3)	**Silica fume (kg/m^3)**	**W/C**	**Aggregates, 0-7 mm (kg/m^3)**	**Aggregates, 7-16 mm (kg/m^3)**	**Super plasticizer (kg/m^3)**
P	400	--	0.55	1038	692	0.6
S	380	20	0.55	1034	689	0.6
T	360	40	0.55	1030	686	0.6

2.3. Polymerization and freeze-thaw test

In order to perform the freeze thaw cycle, the specimens were dried oven of 105 ±5 °C for 24 hours after curing days. The cooled specimens were waited for 24 hours in vinyl acetate monomer in atmospheric conditions. After this, they were kept at 60 °C for 6 hours for the polymerization. Then, they were subjected to freeze–thaw cycles experiment compliant to TS EN 15177 standard (TSE CEN/TR 15177, 2012). According to this standard, samples were placed in the freeze-thaw cabin, which was pre-adjusted to -20±2 °C and was kept in the cabin for 8 hours. After freezing process was finished, the specimens were kept in water for 4 hours at 13± 8 ºC. Totally 56 freeze-thaw cycles were applied to the samples. Then, the ultrasonic pulse velocity and compressive strength experiments of samples were carried out.

3. RESULTS

3.1. Compressive strength

In the current study, the compressive strengths of the concretes strengthened with polymer including phosphazene subjected to freeze–thaw cycles were examined experimentally and then modelled using Taguchi based multiple regression. The rate of phosphazene in polymer was used as 0 %, 1 % and 2 %. The silica fume was used 0 %, 10 % and 20 % of cement weight. Moreover, the specimens were cured at 20±2 ºC for 3, 7 and 28 days. Table 4 shown the compressive strength results of the specimens.

Table 4. *The results of compressive strength of the concretes strengthened with polymer including phosphazene subjected to freeze–thaw cycles*

Phosphazene percentage, (%)	Silica fume percentage, (%)	Curing time, (Day)	Compressive Strength (MPa)
1	1	1	24.03
1	2	2	28.51
1	3	3	23.03
2	1	2	49.15
2	2	3	54.58
2	3	1	52.33
3	1	3	56.79
3	2	1	61.1
3	3	2	65.91

The Taguchi analysis was carried out for the compressive strength of the concretes strengthened with polymer including phosphazene subjected to freeze–thaw cycles. In this study, the loss function was used to find the deviation in between the required and experimental values (Pshadke, 1995; Ross, 1996). In the current study, "higher is better" loss function was selected because the higher compressive strength of the samples is better. The LB loss function (L_{ij}) were given in Equation 1:

$$L_{ij}=\frac{1}{r_a}\sum_{i=1}^{r_a}\frac{1}{y_i^2} \qquad (1)$$

Equation 1 is the loss function of performance no i during the test number j. The numbers of tests in a trial are r_a. The value measured for each test is y. The S/N rate (η) for this loss function were given Equation 2 (Pshadke, 1995; Ross, 1996).

$$S/N_{LB}=-10\log(L_{ij}) \qquad (2)$$

The S/N rates were calculated using the experimental variables in Table 2.

The S/N rates of the compressive strength of concrete strengthened with polymer including phosphazene subjected to freeze-thaw cycles were shown in Table 5.

Table 5. *S/N rates for the compressive strength of concrete strengthened with polymer including phosphazene subjected to freeze–thaw cycles*

	S/N rates		
	Level 1	**Level 2**	**Level 3**
Percentage of phosphazene in polymer, P (%)	32.54	33.00^{s}	32.28
Percentage of silica fume, S (°C)	32.12	33.10^{s}	32.60
Curing time, T (%)	27.93	34.26	35.64^{s}

^{s} Optimum level

Mean S/N rate=32.61.

As Table 5 was examined, the highest compressive strength was obtained from samples that were containing silica fume 5 % at 28 days and used the polymer including phosphazene 1%. To increase the mechanical properties and durability properties of concrete, it must be decreased the gaps and cracks. It is possible to say that the polymer impregnation method is successful in reducing these gaps and cracks. Thus, the mechanical properties and durability properties increase by using of this method (Bal, 1998; Sidney and Young, 1981). The reason for this increase is: it occurs the combination of polymer molecules having polar groups by physical links by the strict adhesion of them to each other (Tanaka et al., 2002; Yalçın, 1998). Furthermore, a continuous polymer phase increases the interfacial transition zone in between the cement paste and aggregate (Satish and Ohama, 1994; Bhutta et al., 2013). This study was found that the use of 1% phosphate in the polymer increased the compressive strength of concrete.

Furthermore, the Taguchi based multiple regression in predicting the compressive strength of concrete strengthened with polymer including phosphazene subjected to the freeze–thaw cycles was in this study. The proposed equation was given bellow.

$$F_c = 46.16 - 20.97 \times P_1 + 5.86 \times P_2 + 15.11 \times P_3 - 2.84 \times S_1 + 1.90 \times S_2 + 0.93 \times S_3 + 0.34 \times T_1 + 1.70 \times T_2 + 1.36 \times T_3 \quad (3)$$

where

F_c= Compressive strength

P_{1-3}= The levels of phosphazene

S_{1-3}= The levels of silica fume

T_{1-3}= The levels of curing days

The estimation results obtained using equation 3 was given in Figure 1.

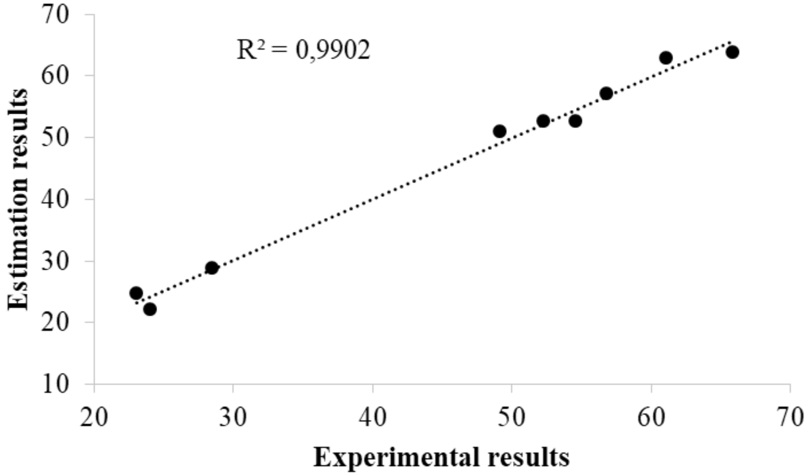

Fig. 1. *The estimation results and experimental results for compressive strength of concrete strengthened with polymer including phosphazene subjected to freeze–thaw cycles*

According to Fig. 1, the proposed equation 3 estimated the compressive strength of concrete strengthened with polymer including phosphazene subjected to the freeze–thaw cycles with 99.02% accuracy. Thus, it was found that this equation can be used to find the compressive strength of concrete containing silica fume strengthened with polymer including phosphazene after subjected to freeze-thaw cycles.

3.2. Ultrasonic pulse velocity

The ultrasonic pulse velocity (UPV) is the determination of the travel time of an ultrasound sent to the concrete (Awal and Shehu, 2015; Lin et al., 2011). If the UPV is large, it thought that the mechanical properties of concrete are good. Furthermore, the UPV is a good method to evaluate the concrete (Al-Rousan, 2015). This method gives an idea the cracks or gaps of the concrete (Güneyisi et al., 2015). The UPV of concrete strengthened with polymer including phosphazene subjected to freeze-thaw cycles were found in the current study. The results were given in Table 6.

Table 6. *The results of UPV of concrete strengthened with polymer including phosphazene subjected to freeze–thaw cycles*

Phosphazene percentage, (%)	Silica fume percent, (%)	Curing time, (Day)	UPV (km/s)
1	1	1	2.58
1	2	2	3.5
1	3	3	3.41
2	1	2	3.98
2	2	3	4.07
2	3	1	4.42
3	1	3	4.24
3	2	1	4.55
3	3	2	4.78

When examined in the table 6, it is understood that the most significant decrease of ultrasonic pulse velocity occurred in samples in which phosphazene was not used. It is understood by this study that impregnation polymer with phosphazene process increases the quality of concrete. Concretes, which are more resistant against freeze-thaw, can be produced by the impregnation of polymer with phospazene.

Taguchi analysis were used to evaluate the effect of each variables on the UPV found in the experimental study. The variables in Table 2 were selected in the calculation of the S/N. The S/N values for the UPV of concrete strengthened with polymer including phosphazene exposed to freeze-thaw cycles were shown in Table 7.

Table 7. *S/N rates of the UPV of concrete strengthened with polymer including phosphazene subjected to freeze–thaw cycles*

	S/N rates		
	Level 1	**Level 2**	**Level 3**
Percentage of phosphazene in polymer, P (%)	10.03	10.38	11.21[s]
Percentage of silica fume,S (%)	9.20	11.22[s]	11.21
Curing time, T (day)	8.37	11.21	12.04[s]

[s] Optimum levels

Mean S/N rate=10.54.

The larger S/N rates must provide the larger ultrasonic pulse velocity. As it can be seen from Table 7, the largest UPV value was obtained from samples that were containing silica fume 5 % at 28 days and used the polymer including phosphazene 2 %. Moreover, Taguchi based multiple regression in predicting the UPV of concrete strengthened with polymer including phosphazene subjected to the freeze–thaw cycles was in the current study. The proposed equation was given bellow.

$$UPV = 3.9478 - 0.784 \times P_1 + 0.209 \times P_2 + 0.576 \times P_3 - 0.348 \times S_1 + 0.092 \times S_2 + 0.256 \times S_3 - 0.098 \times T_1 + 0.139 \times T_2 - 0.041 \times T_3 \qquad (4)$$

where

UPV= Ultrasonic pulse velocity

$P_{1\text{-}3}$= The levels of phosphazene

$S_{1\text{-}3}$= The levels of silica fume

$T_{1\text{-}3}$= The levels of curing days

The estimation results obtained using equation 4 was shown in Figure 1.

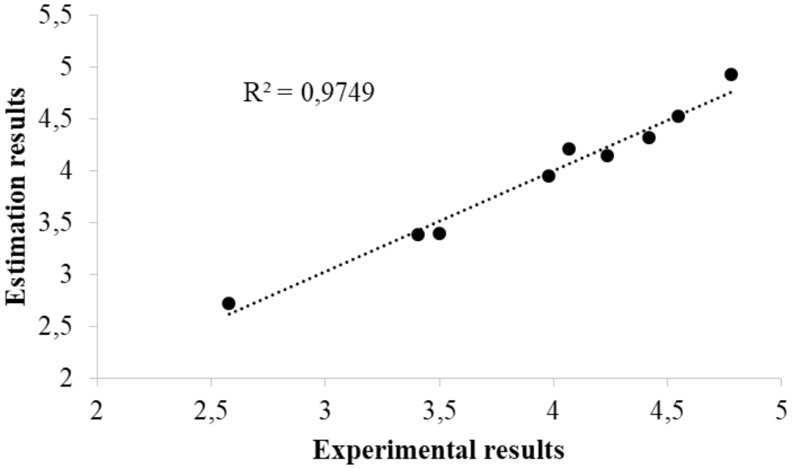

Fig. 2. *The estimation results and experimental results for the UPV*

It can be seen from Fig. 2 that the proposed equation 4 estimated the UPV of concrete strengthened with polymer including phosphazene exposed to the freeze–thaw cycles with 97.49 % accuracy. As a result, it can be said that this equation can be used to find the UPV of concrete the concretes containing silica fume strengthened with polymer including phosphazene after exposed to freeze-thaw cycles.

3.3. The relative dynamic modulus of elasticity

In this study, the relative dynamic modulus of elasticity (RDME) of samples was found using the UPV at the end of 56 freeze-thaw cycle. The equation used in calculating the RDME of samples was given in below (ASTM C666, 2015).

$$RDME = 100 \times \left(\frac{UPV_L}{UPV_F}\right)^2 \qquad (5)$$

where

RDME=The relative dynamic modulus of elasticity,

UPV_F= The result of ultrasonic pulse velocity of sample at 0 cycles,

UPV_L= The result of ultrasonic pulse velocity of sample at 56 cycles.

The RDME results of specimens were shown in Fig. 3.

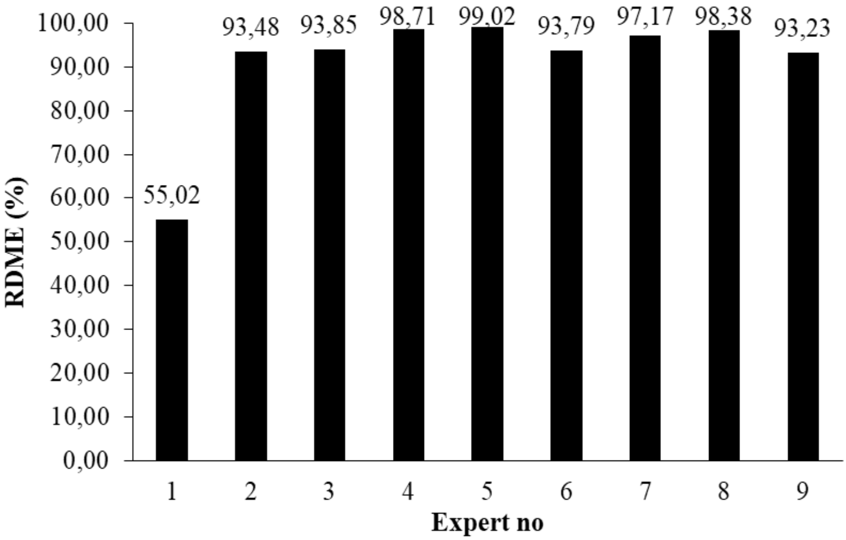

Fig. 3. *RDME results of specimens*

It can be seen from Fig. 3 that the lowest RDME was obtained from specimen in first expert number. The phosphazene level 1 (0%), silica fume level 1 (0%) and curing day level 1 (3 day) were used in this specimen. Moreover, the highest RDME was obtained from specimen in five expert number. The phosphazene level 2 (1%), silica fume level 2 (5%) and curing day level 3 (28 day) were used in this specimen. According to these results, the use of 1% phosphazene and 5 % silica fume in the polymer improved the resistance of concrete against freeze-thaw.

4. CONCLUSIONS

In the current study, the compressive strength and UPV changes of the concretes containing silica fume strengthened with polymer including phosphazene exposed to freeze-thaw cycles were examined and then modelled. In the experimental study to decrease the quantity of experiments and to find the maximum compressive strength and UPV values Taguchi method was used. According to Taguchi analysis, the highest compressive strength was obtained from samples to which cure was applied for 28 days, which contained 5% silica fume and in which polymer containing 1% phosphazene was used. Differently, the highest UPV was obtained in samples to which cure was applied for 28 days, which contained 5% silica fume and in which polymer including 2% phosphazene was used. Besides, the UPV of concretes was deterimed before and after being subjected to freeze-thaw in order to find freeze-thaw damage. The RDME's of samples were calculated. The freeze-thaw damage varied from 0.98% to 44.98 %. It was observed that the polymer impregnation containing phosphazene decreased freeze-thaw damage significantly. In the current study, it was determined that the impregnation of polymer including phosphazene to concrete can be useful in concretes in which freeze-thaw damage may occur. Furthermore, the compressive strength and UPV of concrete exposed to freeze-thaw were modelled using the Taguchi based multiple regression. The proposed equation 3 and 4 estimated the compressive strength and UPV with 99.02 and 97.49% accuracy, respectively.

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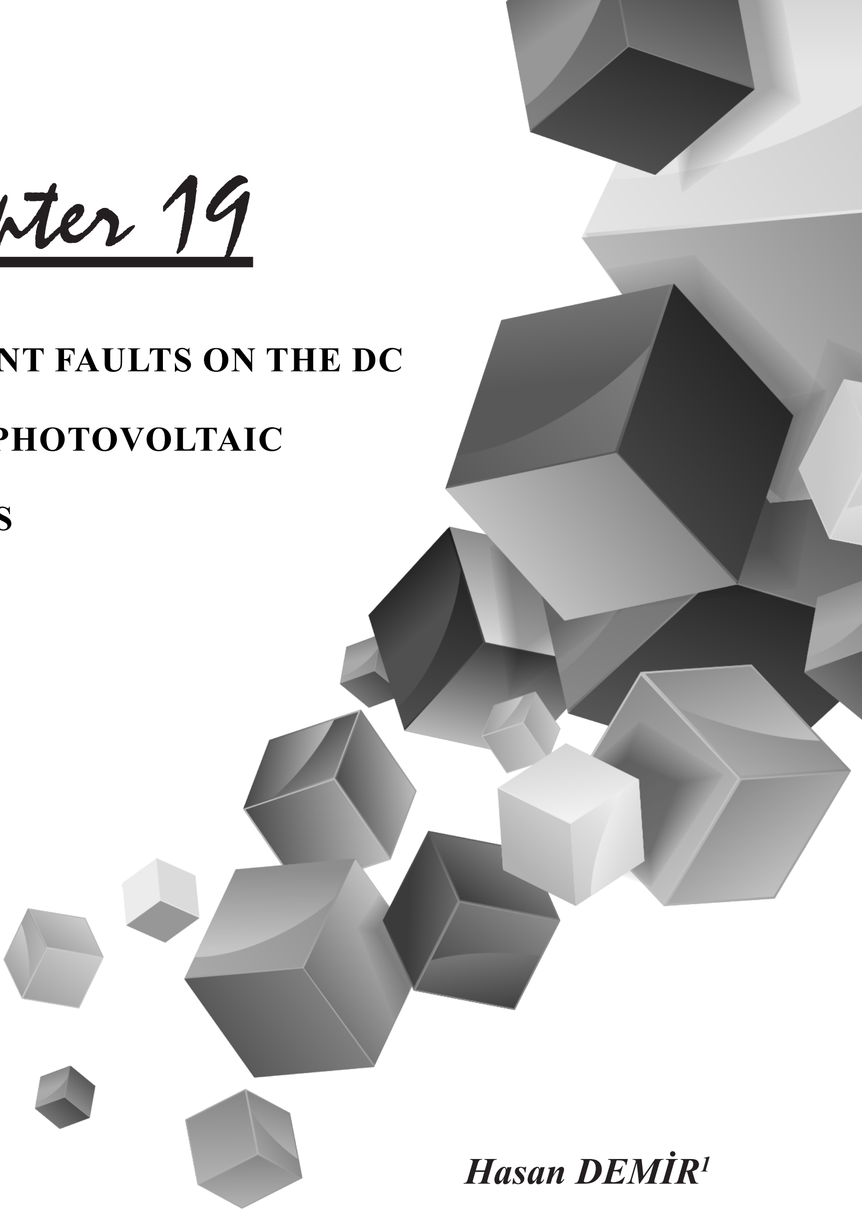
Chapter 19

FREQUENT FAULTS ON THE DC SIDE IN PHOTOVOLTAIC SYSTEMS



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1. Introduction

Depending on the developing industry and modern life in the world, the need for energy is increasing day by day. Traditionally, the energy is provided from hydro carbon sources, nuclear sources, water sources, etc. In order to meet the increasing energy need and to reduce the damage caused by energy production to nature, the tendency towards green power technologies has increased (Alsafasfeh et al. 2018; Despotou et al. 2010; IEA 2007; Surek 2003). Green energy technology consists of renewable energy sources such as solar, wind, hydro, tidal. The best method among renewable energy sources and the method whose number is rapidly increasing is to obtain electricity from the sun. Solar photovoltaic panels (PV) are systems that convert solar energy into electrical energy. Despite the developing technology today, the efficiency of PV is between 15 and 19 percent (Coşgun and Uzun 2017). PVs are installed outdoors and are exposed to environmental factors such as rain and snow. This situation can reduce the performance of PVs depending on both environmental and electrical reasons. Studies have shown that the annual power loss due to faults is 18.9 percent (Firth, Lomas, and Rees 2010). Power losses due to faults increase energy generation costs.

Faults that occur in PVs affect the normal operating performance of the panels. In order to minimize the efficiency losses caused by faults, faults should be detected. In this study, a brief summary about PVs is given and various faults occurring in the DC side of PVs are explained.

2. Overview of Photovoltaic Panel

As a result of a series or parallel connection of many solar cells shown in Figure 1, PV modules are created. Solar cells consist of different semiconductor such as monocrystalline silicon, polycrystalline silicon, amorphous silicon, Cadmium telluride and copper indium selenide / sulphide (Coşgun and Uzun 2020). Bypass diodes are available between the cell lines to prevent the cells overheating by acting as a receiver while generating energy in sunlight.

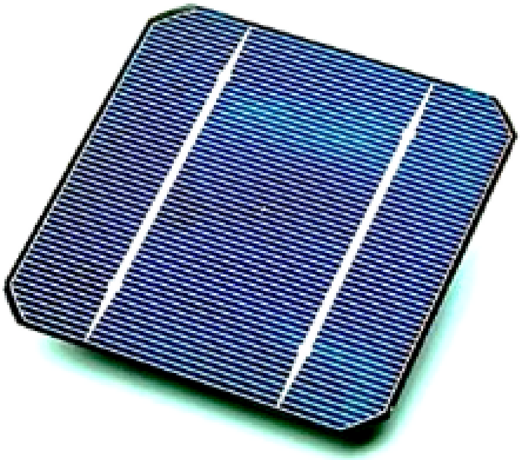


Figure 1. Solar cell (Zhao 2010)

PVs are used in many areas today to meet high energy needs. Besides this, solar cells are used to meet low energy need such as calculators, garden lights. There are many environmental, meteorological and electrical reasons that affect the operation of PVs and cause faults on the DC side.

3. PhotovoltaIc System FaIlures In DC Sıde

We can generally divide the faults that occur in PV into 2 parts: DC side and AC side (Davarifar, Rabhi, and Hajjaji 2013). The basic elements of a solar energy cycle are PV array, DC / AC converter and grid connect inverter. DC / AC converter divides the system into two as DC and AC. The faults on the DC side are explained in this study.

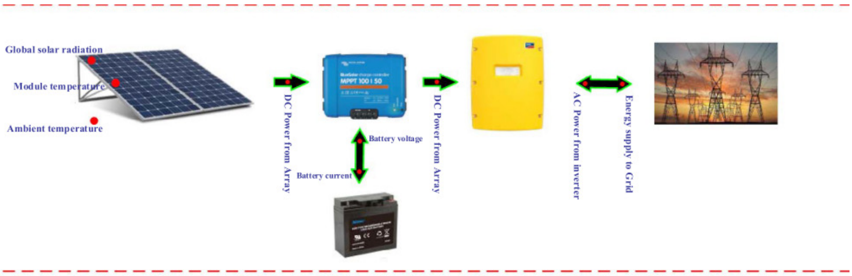


Figure 2. Block Schematic of Solar Energy Conversion System (Madeti and Singh 2017)

3.1. Photovoltaic Ground Fault

PV arrays consist of non-current carrying parts such as modulated frames, metal enclosures, distribution panels and mounting racks. These parts are conductive but do not carry current during normal operation.

Contact of electrically carrying parts with these non-electric parts can cause electrical damage. In order to prevent these damages, all these non-electric but conductive parts must be connected together to ground. Figure 3 shows a grounded PV system using Equipment grounding conductor (Bower and Wiles 1994; Zhao et al. 2011, 2013).

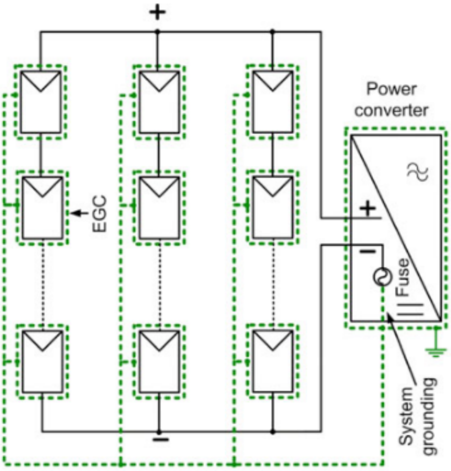
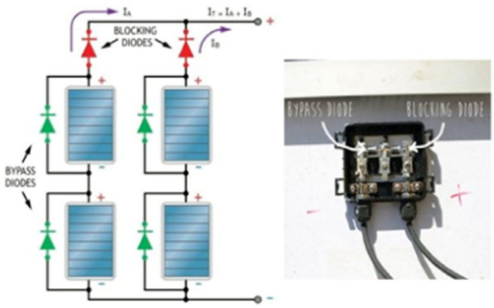


Figure 3. Schematic diagram of grounded PV systems (Bower and Wiles 1994).

3.2. Diodes Fault

While a bypass diode prevents reverse voltage caused by shadowing in the panels, the block diode prevents reverse currents. As a result of over long time exposure to partial shadowing, the diode faults occur in PV panels (Rezgui et al. 2014; Winter, Sizmann, and Vant-Hull 1991). Bypass diode compensates for power losses caused by ghosting. The reverse current is the reason of the hot spot on the panels and it could give seriously damage PV panels. Other reason of diodes faults is the reverse connection or disconnection (Köntges et al. 2014).



(a) (b)

Figure 4. a) Shematic block of bypass and blocking diodes, b) Junction boxes (Mellit, Tina, and Kalogirou 2018).

3.3. Junction Box Fault

Junction box faults are among the most important issues encountered in the field and during testing. Degradation, especially in hot and humid climates, increases the corrosion contact resistance. As a result of this event, the temperature increases at the contact leads and the junction box may melt and erode. Sparking can occur in junction box failure and the PV arrays can be damaged (Chang et al. 2015; Triki-Lahiani, Bennani-Ben Abdelghani, and Slama-Belkhodja 2018). Figure 5 shows PVs damaged by junction box faults.

Figure 5. Junction box faults (Mellit et al. 2018)

3.4. PV Module Fault

PV module faults are usually physical faults. These faults are caused by corrosion, problems in the grounding line, leakage currents in the module, faults in the production phase, and short circuits in the module. Some of faults cause electrical damage and there is a risk of fire. These faults affect system performance and reduce productivity. Figure 6a shows broken glass on the PV module, Figure 6b shows corrosion, Figure 6c and 6d shows bubbles (Köntges et al. 2014; Munoz et al. 2011; Stellbogen 1993).

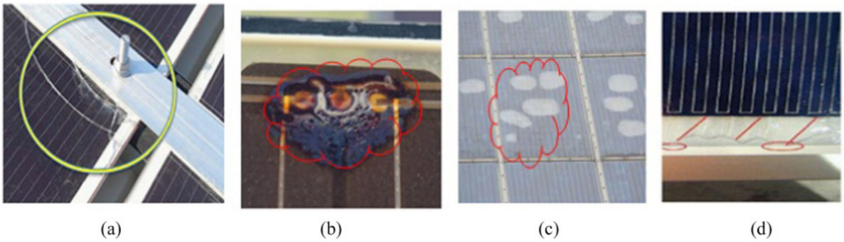


Figure 6. a) Damaged glass, b) corrosion, c) bubbles and d) degradation (Mellit et al. 2018).

3.5. Mismatch Fault

Mismatch faults are caused by changes in electrical parameters between the cell or cells. The main reason for the mismatch fault is that some solar cells cannot generate electricity. Some cells in the PV module cannot produce electricity due to shading, temperature, solar irradiation, while others can. This causes the cell, which cannot generate electricity, to heat up and cause irreversible damage. We can categorize incompatibility faults as temporary and permanent.

3.5.1. Permanent Mismatches

Permanent mismatches is caused by permanent faults in some cells on the panels. Permanent deterioration of some solar cells creates electrical incompatibility with other cells. The most common faults that cause permanent mismatch, such as hot spot, discoloration, delamination, soldering, will be examined under separate headings (Davarifar et al. 2013; Jiang and Maskell 2015).

3.5.2. Temporary Mismatches

Temporary shadowing on PV modules causes mismatch faults. Climatic conditions such as snow, dust and clouds cause shadowing on the panels. In addition, due to the movement of the sun, obstacles such as buildings and trees cause shading on the PV panels.

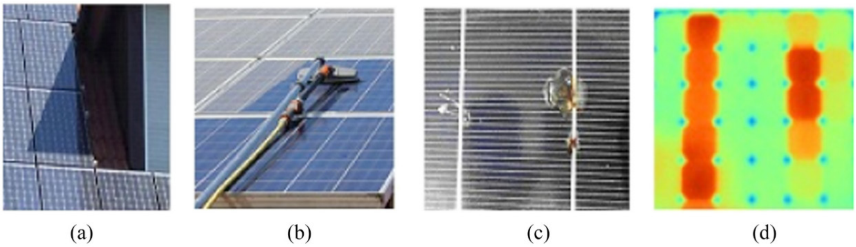

(a) (b) (c) (d)

Figure 7. a) shading, b) dusting, c) solar cell damaged by hot spot, d) hot spots detected by the infrared method (Mellit et al. 2018).

3.6. Hot Spot Faults

Hot spot fault may occur because a solar cell in the PV module cannot generate electricity for any reason. The voltage of the cell that cannot produce current drops and the cell starts to work in reverse bias. As a result, performance starts to decline. Hot spot faults are caused by situations such as high resistance, cold solder points, contamination, dust accumulation, insulation, degradation, partial shadow (GREEN et al. 2012; Kalogirou, Agathokleous, and Panayiotou 2013; Massi Pavan, Mellit, and De Pieri 2011; Solórzano and Egido 2013). In addition, hot spots may occur in cells with damaged bypass diodes and solar panels may be damaged if the heated cell is not intervened. Thermal imaging is generally used to detect hot spot cells (Simon and Meyer 2010; Yang et al. 2010). Hot spots in PV is shown in Figure 8.

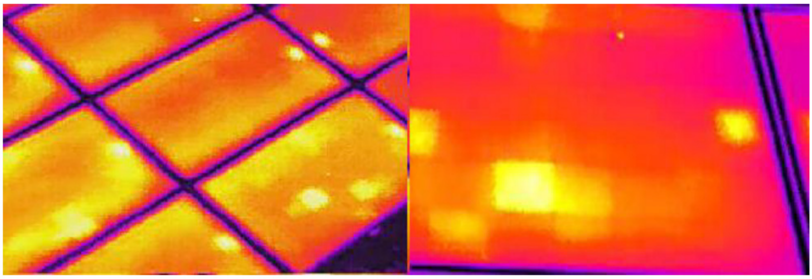


Figure 8. Hot Spots in PV (Alsafasfeh et al. 2018).

3.7. Discoloration and Encapsulant Yellowing

Discoloration occurs by photothermal decomposition of ethyl vinyl acetate (EVA) encapsulant as a result of prolonged exposure to UV rays and high temperatures. Generally, hot and humid environmental conditions are the main cause of discoloration. Visually detectable discoloration causes corrosion, leading to a decrease in series resistance (Park et al. 2013; Sinha et al. 2020; Wohlgemuth, Kempe, and Miller 2013). Examples of discoloration are given in Figure 9.

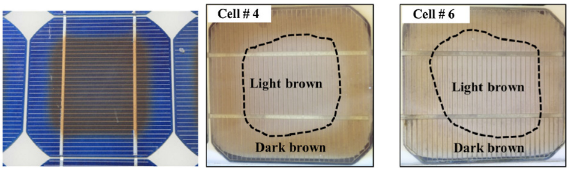


Figure 9. Discolorations (Park et al. 2013; Wohlgemuth et al. 2013).

Yellowing is usually caused by the deterioration of EVA or the deterioration of the adhesive between the solar cell and the glass sheet. The reasons for yellowing are UV rays, humidity and heat. This deterioration causes the solar panel to turn yellow or brown in colour. As a result of the yellowing fault, water penetrates into the solar panel due to the loss of the property of the adhesive between the glass and solar panel in the photovoltaic panel (Munoz et al. 2011; Oreski and Wallner 2009). Yellowing faults in the PV module are shown in Figure 10.

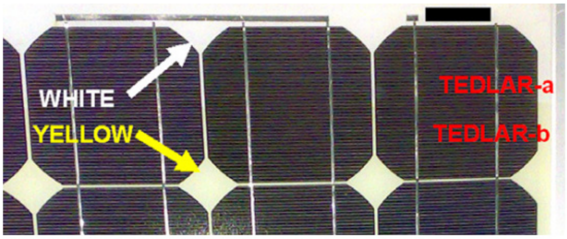


Figure 10. Yellowing area in PV module (Munoz et al. 2011; Oreski and Wallner 2009).

3.8. Thermal Fault

Thermal imaging is based on the principle of detecting infrared radiation caused by the thermal effect. Thermal imaging shows the temperature differences in the environment being displayed. Bubbles can occur behind the PV modules due to adhesive deterioration by the high temperatures. These situations that occur as a result of the high temperature effect can be called thermal faults. Fault detection can be made with thermal imaging due to temperature differences. Figure 11 shows the temperature differences on the PV module due to bubble and fractures by thermal imaging (Munoz et al. 2011).

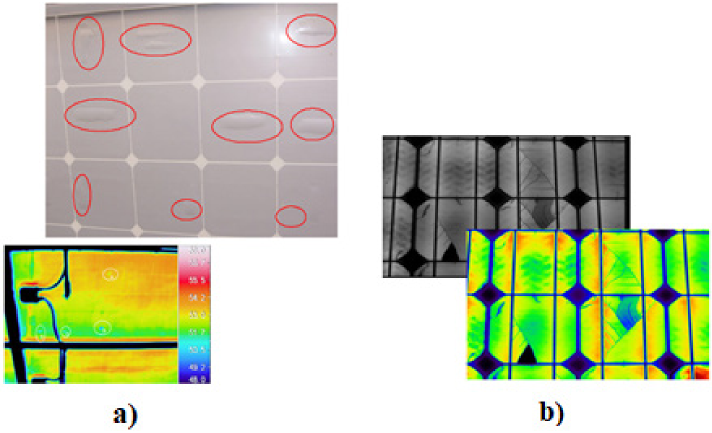


Figure 11. a) Bubbles and thermal image behind the PV module, b) Fractures and thermal image on the PV module (Munoz et al. 2011).

3.9. Delamination

Delamination is the separation between layers on the PV module. There are encapsulant (EVA) and solar cell layers on the PV module. Especially in hot and humid climates, water droplets are formed between EVA and solar cell. Corrosion occurs due to water droplets and decomposition occurs between layers. In addition, corrosion affects the solder connections and cell interconnections, increasing the resistance and causing power loss in the PV module. Figure 12 shows the cross-sectional view of the area where delamination occurred on the PV module (Berman, Biryukov, and Faiman 1995; Gxasheka, Van Dyk, and Meyer 2005; Kempe 2006; Morita et al. 2003; Wenham et al. 2011).

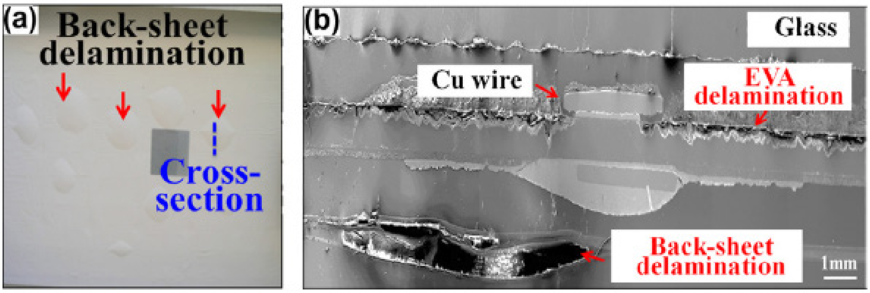


Figure 12. Delaminated area; a)Back-sheet, b) the cross-sectional view of the area (Park et al. 2013).

3.10. Anti-reflective Coating Faults

PV modules are covered with an anti-reflective coating to prevent the reflection of sunlight. This coating allows more sunlight to reach the active area of the solar cells and increases performance. Anti-reflection coating is made using such as silicon dioxide, aluminium nitride and silicon nitride materials. Solar-induced ultraviolet radiation is the main reason for the degradation of the anti-reflection coating. The colour of the reflective coating that started to deteriorate changes and the sunlight reaching the cell starts to decrease (Krugel et al. 2013; Munoz et al. 2011).

Anti-reflection coatings made using different materials increase the performance of PV. While this is an advantage, as a disadvantage, the coating deteriorates over time and reduces the performance. Hot spots may occur on the PV module in the later stages of deterioration.

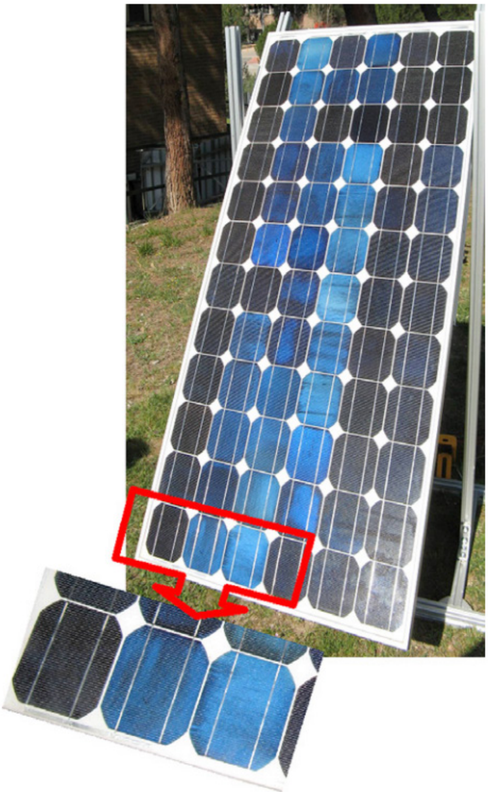


Figure 13. The colour change due to deterioration of the anti-reflective coating in PV module (Munoz et al. 2011).

4. Conclusion

Today, PV modules are the key elements of clean and renewable energy production from solar energy. In PV plants, the reliability and profitability of the enterprise is one of the most important issues, and electricity production with PV modules is increasing day by day. This increase has made the faults that cause power losses in PV modules an important issue and the faults have increased the costs of enterprises. Faults in PV modules can occur for a number of reasons. Majority of faults are caused by environmental conditions such as temperature, humidity and the structure of PV modules. Literature researches are helpful resources to understand these faults. In this study, important faults on the DC side of a Solar Energy Conversion System are explained. Causes of faults and situations that may occur as a result are mentioned. This study has been prepared to guide researchers doing research in the scientific field and to explain the faults experienced in small or large-scale PV plants.

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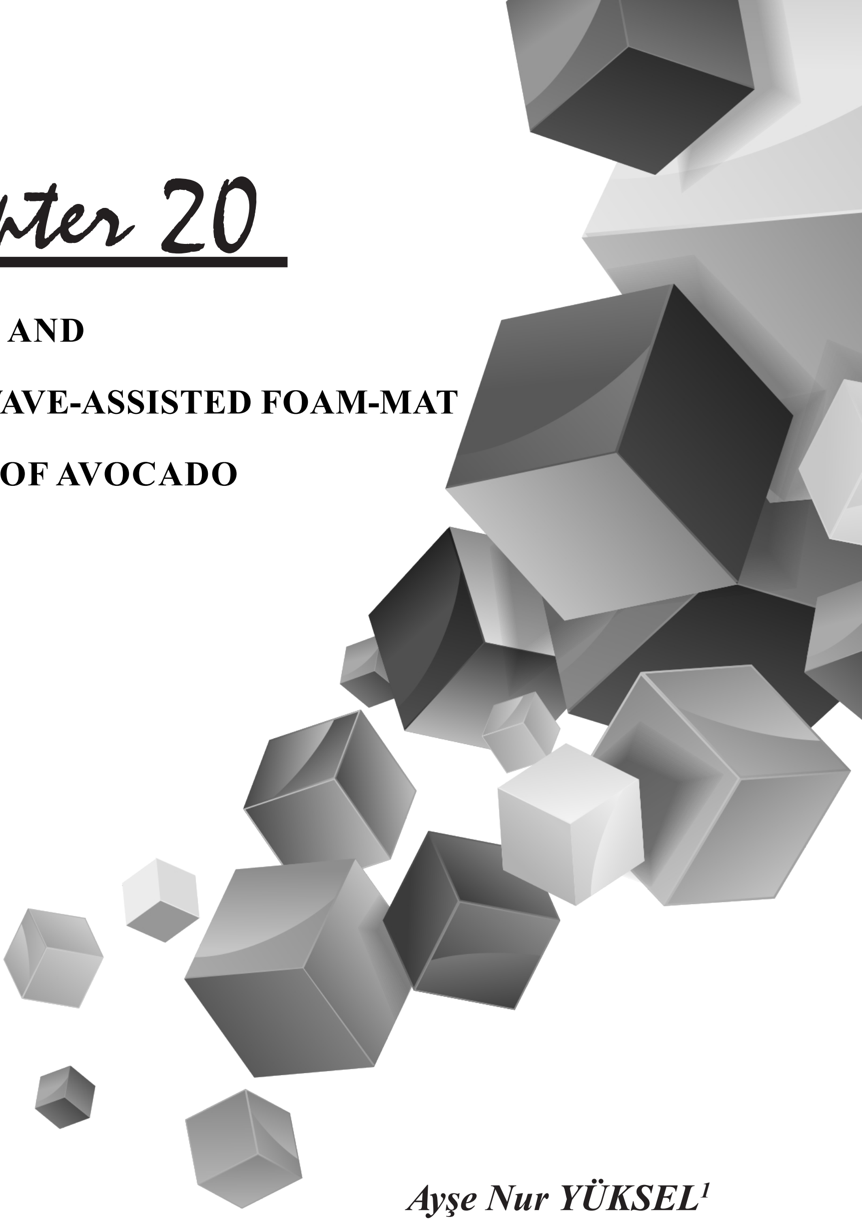
Chapter 20

HOT-AIR AND MICROWAVE-ASSISTED FOAM-MAT DRYING OF AVOCADO



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1. Introduction

Avocado (*Persea americana* Mill.) is an oleaginous fruit which belongs to *Lauraceae* family and grows in tropical regions. It is consumed all over the world. The production of avocado increased in two decades, in 2016 5.5 million of tones of avocado produced in the world. Mexico is the major producer with 1.9 million tones (Colombo & Papetti, 2019). Avocado is very rich in nutrition as vitamins, proteins, carotenoids, lipids, polyphenols, unsaturated fatty acids and fibers (Ali et al., 2008; Araujo, Rodriguez-Jasso, Ruiz, Pintado, & Aguilar, 2018).

Drying is the most common used method to increase the shelf-life of fruits and use of these products in different food formulations. Foam mat drying is a technique where liquid or semi-liquid foods are whipped in order to obtain a stable foam. The air is trapped in foam by the presence of foaming agent and stabilizers, then foam is dried. Drying can be performed by using various methods as hot-air, microwave, vacuum and freeze-drying techniques (Thuwapanichayanan, Prachayawarakorn, & Soponronnarit, 2008). Foam-mat drying provides simple and inexpensive drying, accelerated drying rates at lower temperatures and the powder which is produced is tend to rehydrate instantly in cold water with enhanced product quality (Kadam & Balasubramanian, 2011). As foaming agent, gelatin, egg albumin, carboxymethyl cellulose, glycerol mono stearate (GMS), methyl cellulose, soy protein isolate, whey protein concentrate and xanthan gum can be used. GMS was used in the studies of Chakraborty, Mazumder, and Banerjee (2017) and Zheng et al. (2013) for foam-mat drying of potato and berry puree, respectively. Kadam and Balasubramanian (2011) obtained tomato powder by hot-air foam-mat drying with adding various percentages of egg albumin (0-20 %, w/w). In literature, there are studies about foam-mat drying of different kinds of fruits and vegetables in which drying methods e.g., air, freeze and microwave and foaming agents used were different (Qadri, Srivastava, & Yousuf, 2019; Sangamithra, Venkatachalam, John, & Kuppuswamy, 2015).

There is no investigation in the literature about the foam-mat drying of avocado puree. Therefore, this study aimed to investigate how the change of temperature and power intensity effect the drying rate and time during hot-air and microwave drying processes, respectively, to calculate the activation energy for both drying method and to find the best fitted thin-layer drying models for microwave and hot-air dryings of avocado-foam by using statistical parameters.

2. Materials and methods

2.1 Materials

The mature avocados and commercial pasteurized liquid egg whites were obtained from upper market in Alanya, Turkey. The mature avocados were peeled and the puree was obtained by using home type kitchen blender (1000W power, SHB 3107, Sinbo, Turkey).

2.2 Methods

2.2.1 Foam Preparation

150g of avocado puree and 30% (by weight) of liquid egg white as a foaming agent were added to the glass beaker (2 liters). In order to obtain avocado foam, the home type kitchen blender (at a maximum speed of 1000W power, SHB 3107, Sinbo, Turkey) was used for 6 minutes. The total amount of avocado foam was 20.00±0.20g for each drying experiment. Samples were placed flat as a slab 10.50 cm x 0.2 cm diameter x thickness so drying occurs from one side.

2.2.2 Hot-Air Drying

The avocado foam was dried in a convective oven (Memmert, UF 110, Germany) at 60, 70 and 80°C temperature and at 20% ventilation rate. The weight loss was measured for every 5 min until the constant weight was reached.

2.2.3 Microwave Drying

The microwave drying process (Arçelik MD574, Turkey) were performed at 120, 460 and 700W microwave powers. Avocado foam was removed periodically (10s intervals) from the microwave oven and weighed. When the change in the mass of the samples dropped to 0.01 (g) between the two measurements, experiments were finished.

2.3 Mathematical modeling of drying data

The moisture ratio (MR) was computed as $(m_t-m_e)/(m_i-m_e)$ where m_t is the moisture content at time t, m_i and m_e are the initial and equilibrium moisture contents (kg/kg dry solid (DS)), respectively. The calculation of drying rate (R) was made as $(-L_s/A)*((X_{t+1}-X_t)/(t_{t+1}-t_t))$, where R is the drying rate (kg/ m^2*h); L_s is the weight of dry solid (kg); A is the drying area (m^2); X_t is the moisture content at specific time (kg/kg DS) and t is time (h).

Moisture ratio as a function of drying time was determined by using five thin-layer drying models as Page (Eq. (1)) (Diamante & Munro, 1993), two-term (Eq. (2)) (Henderson, 1974), Midilli and others (Eq. (3)) (Midilli, Kucuk, & Yapar, 2002), Peleg (Eq. (4)) (da Silva, Rodrigues, Silva, de Castro, & Gomes, 2015) and Silva and others (Eq. (5)) (D. I. Onwude, N. Hashim, R. B. Janius, N. M. Nawi, & K. Abdan, 2016b).

$$MR = \exp(-k * t^n) \quad (1)$$

$$MR = a * \exp(-k_1 * t) + b * \exp(-k_2 * t) \quad (2)$$

$$MR = a * \exp(-k_1 * t^n) + b * t \quad (3)$$

$$MR = 1 - t/(a + b * t) \tag{4}$$

$$MR = \exp(-a * t - b\sqrt{t}) \tag{5}$$

where a, k, n, k_1, k_2 and b are constants in models and *t* is time.

2.4 Effective moisture diffusivity

Fick's second law were used in calculation of the effective moisture diffusivity which is used for long drying times and infinite slab geometry in one dimension. First term of the series could be taken into account (Eq. (6)) when the assumptions were accepted such as a) water removal occurs with diffusion; b) volume of sample during drying was constant; c) the distribution of temperature was uniform and coefficient of diffusion was constant during drying (Chayjan & Kaveh, 2014; Crank, 1975).

$$MR = \frac{8}{\pi} * exp(\frac{-D_{eff} * \pi^2 * t}{4 * L^2}) \tag{6}$$

where D_{eff} is the diffusion coefficient (m^2 s^{-1}); L is the half thickness of sample (m) and t is the drying time (s). D_{eff} can be determined by plotting ln(MR) versus time (sec) (Doymaz & Ismail, 2011).

2.5 Estimation of activation energy

Activation energy (E_a) (kJ/mol) of convective drying was computed by an Arrhenius type relationship due to the temperature dependence of the effective diffusivity (Eq. (7)).

$$D_{eff} = D_0 \exp\left(-\frac{Ea}{RT}\right) \tag{7}$$

Where D_0 is the pre-exponential factor (m2/s), R is the universal gas constant (kJ/mol* K) and T is the absolute temperature (K). From the slope of the straight line of $\ln D_{eff}$ versus 1/T, the activation energy was computed (Kumar, Sarkar, & Sharma, 2012).

For microwave drying, the ratio of the microwave power intensity to sample amount instead of the temperature was used for calculation of the E_a (Dadali, Demirhan, & Ozbek, 2007). Where P is microwave power intensity (W) and m is the mass of sample (g) (Eq. (8)).

$$D_{eff} = D_0 \exp\left(-\frac{Ea\, m}{P}\right) \tag{8}$$

2.6 Data analysis

The best fitted model to experimental drying data was determined by regression analysis using Sigma Plot software (Erkrath, Germany). To evaluate the goodness of fitted model, correlation coefficient (R^2), residual sum of squares (RSS), the reduced chi-square (χ^2) and root mean square error (RMSE) were computed using equations below (Eq. (9-11)) (McMinn, 2006):

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pred,i})^2}{N - n_p} \tag{9}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pred,i})^2} \tag{10}$$

$$RSS = \sum_{i=1}^{N}(MR_{exp,i} - MR_{pred,i})^2 \tag{11}$$

where $MR_{exp,i}$ is the experimental moisture ratio; $MR_{pred,i}$ is the predicted moisture ratio; N is the number of data points and n_p is the number of parameters in model.

3. Results and discussion

3.1 Drying of avocado-foam

Drying curves are given in Figures 1 and 2. Drying times of convectional hot-air drying were reduced to 3.13, 19.35 and 21,88 % when the drying temperature increased from 60 to 70°C, 70 to 80°C and 60 to 80°C, respectively. Drying rates were increased to 5.17, 26.23 and 32.76% for the temperature increase from 60 to 70°C, 70 to 80°C and 60 to 80°C, respectively. On the other hand, drying times were shortened by 81.82, 29.17 and 87.12 % for microwave drying from 120 to 460 W, 460 to 700 W and 120 to 700 W, respectively. Furthermore, the increments of the drying rate were observed as 433.19, 35.74 and 623.77 % for the increasing microwave power intensity from 120 to 460 W, 460 to 700 W and 120 to 700 W, respectively. The drying times of microwave dried avocado- foam were extremely low compared to the convective dried ones. Similarly, drying rates of microwave drying were much higher than convective drying. The reason of this, water molecules absorbs and transmits the microwave energy and provides uniform heat generation with faster boiling of water than the convective drying (Ilter et al., 2018). The experimental results illustrated that the free moisture contents of avocado-foams decreased depending on time. Increase in air temperature and microwave power intensity speeded up the drying process, thus shortened the time. It demonstrated that heat and mass transfer through the avocado-foam were faster at higher temperature and microwave intensity. Similar findings were reported for foam-mat dried tomato juice (Kadam & Balasubramanian, 2011), banana (Sankat & Castaigne, 2004; Thuwapanichayanan et al., 2008) and drying of garlic puree with hot-air and microwave drying (Ilter et al., 2018). For both drying methods, there were three periods: warming-up, constant and falling rate. Similar result was obtained in the study where convective, microwave, microwave-convective and microwave-vacuum drying of lactose powder (McMinn, 2006). However, Demirhan and Ozbek (2010) and Akpinar, Bicer, and Yildiz (2003) observed only the falling rate period during the microwave drying of purslane and hot-air drying of red pepper, respectively.

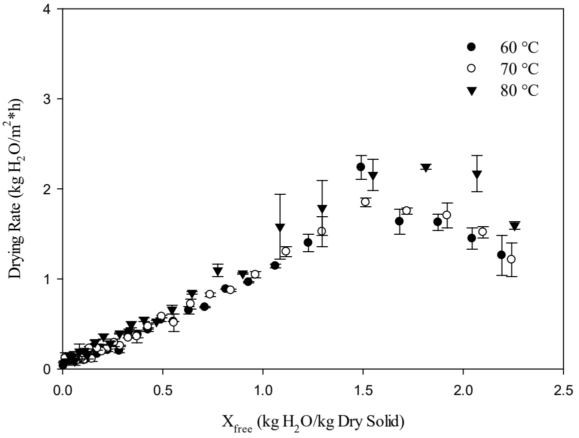

Figure 1. Drying rates for convectional drying

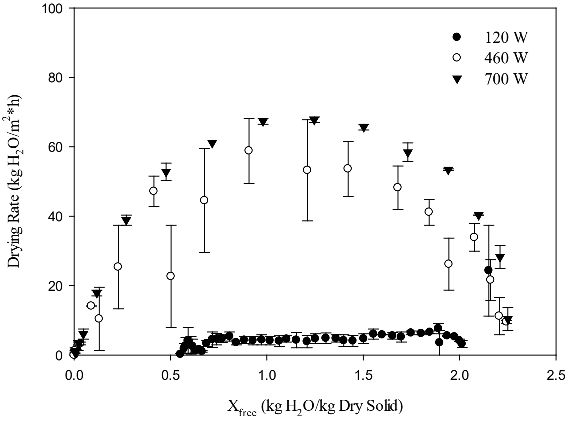

Figure 2. Drying rates for microwave drying

3.2 Drying kinetic of avocado-foam

Five different thin-layer drying models as mentioned in Section 2.3 were used to describe the effect of drying temperature and microwave power intensity on the drying kinetic of avocado-foam. The results of fitting are displayed in Table 1 and 2. Low RMSE, RSS and χ^2, high R^2 values indicate good fitting of the model to the experimental drying data of avocado-foam. Among those models, for convective drying Silva and others model was observed to most appropriate. The correlation coefficients of avocado-foam were obtained between 0.9857-0.9993. The values of R^2 of Silva and others model were more than 0.99 indicating good fit. For microwave drying, Midilli and others model was observed to good fit with R^2 more than 0.99 (Figure 3.). However, even if Page model also gave high R^2 values, low RMSE, RSS and χ^2 values were found to be higher than Midilli and others. In the study of foam mat drying at 50, 60, 70 and 80 °C of yellow mombin pulp, de Freitas et al. (2018) found Midilli model as the best mathematical fit at the temperature of 60, 70 and 80 °C, whereas the Wang and Singh model was showed the best fit at 50 °C.

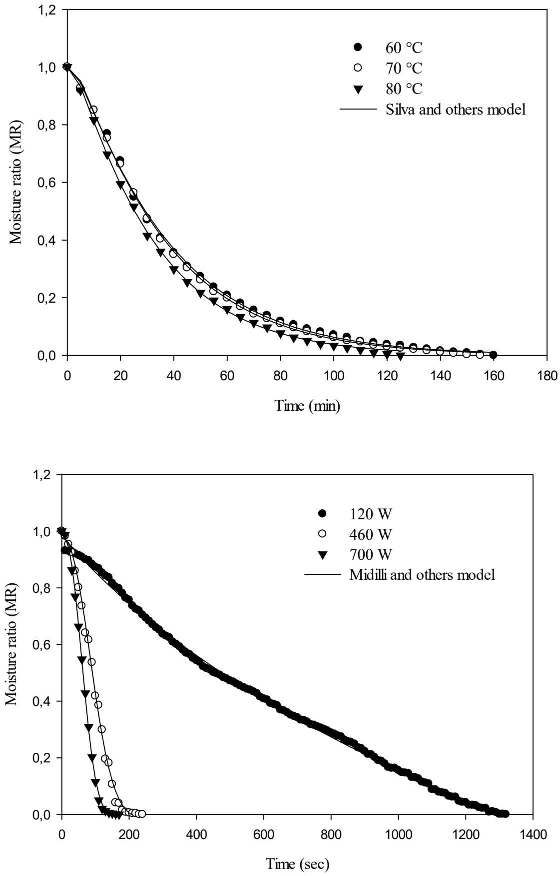

Figure 3. Comparison of experimental hot-air and microwave drying data to predicted values of best fitting models

Table 1. Model parameters and statistical results for hot-air drying

Drying Models	Drying Parameters	60 °C	70 °C	80 °C
Page	R^2	0.9978±0.0001	0.9985±0.0002	0.9988±0.0004
	RMSE	0.0138±0.0005	0.0116±0.0006	0.0104±0.0015
	RSS	0.0062±0.0006	0.0043±0.0005	0.0029±0.0008
	χ^2	0.0002±0.0000	0.0002±0.0001	0.0002±0.0001
	k	0.0135±0.0001	0.0124±0.0000	0.0166±0.0018
	n	1.1500±0.0124	1.1733±0.0193	1.1660±0.0180
Two-term	R^2	0.9960±0.0007	0.9958±0.0007	0.9958±0.0005
	RMSE	0.0184±0.0015	0.0189±0.0016	0.0192±0.0013
	RSS	0.0110±0.0019	0.0115±0.0019	0.0096±0.0012
	χ^2	0.0004±0.0001	0.0004±0.0001	0.0005±0.0001
	a	0.5310±0.0009	0.5337±0.0014	0.5297±0.0017
	k_1	0.0258±0.0010	0.0259±0.0016	0.0322±0.0011
	b	0.5310±0.0009	0.5337±0.0014	0.5297±0.0017
	k_2	0.0258±0.0010	0.0259±0.0016	0.0322±0.0011
Midilli and others	R^2	0.9981±0.0002	0.9988±0.0000	0.9989±0.0003
	RMSE	0.0127±0.0006	0.0104±0.0004	0.0098±0.0014
	RSS	0.0053±0.0006	0.0034±0.0002	0.0025±0.0007
	χ^2	0.0002±0.0000	0.0001±0.0000	0.0001±0.0000
	a	1.0207±0.0035	1.0180±0.0036	1.0160±0.0027
	k	0.0151±0.0008	0.0134±0.0004	0.0189±0.0023
	n	1.1297±0.0235	1.1607±0.0242	1.1345±0.0210
	b	2.69E-05±1.83E-05	4.18E-05±5.42E-07	-3.08E05±3.99E-07
Peleg	R^2	0.9863±0.0024	0.9857±0.0022	0.9884±0.0001
	RMSE	0.0337±0.0029	0.0349±0.0028	0.0318±0.0001
	RSS	0.0374±0.0069	0.0392±0.0061	0.0263±0.0001
	χ^2	0.0012±0.0002	0.0013±0.0002	0.0011±0.0000
	a	36.2478±1.8290	36.8924±2.6920	29.4054±1.7685
	b	0.7372±0.0103	0.7283±0.0098	0.7270±0.0140
Silva and others	R^2	0.9987±0.0003	0.9993±0.0000	0.9992±0.0001
	RMSE	0.0105±0.0009	0.0081±0.0002	0.0083±0.0007
	RSS	0.0037±0.0007	0.0021±0.0001	0.0018±0.0003
	χ^2	0.0001±0.0000	0.0001±0.0000	0.0001±0.0000
	a	0.0309±0.0015	0.0316±0.0025	0.0392±0.0009
	b	-0.0439±0.0036	-0.0486±0.0054	-0.0518±0.0023

Table 2. Model parameters and statistical results for microwave drying

Drying Models	Drying Parameters	120 W	460 W	700 W
Page	R^2	0.9882±0.0040	0.9965±0.0003	0.9984±0.0003
	RMSE	0.0325±0.0027	0.0222±0.0007	0.0151±0.0015
	RSS	0.0998±0.0648	0.0124±0.0009	0.0041±0.0008
	χ^2	0.0011±0.0002	0.0006±0.0001	0.0003±0.0001
	k	1.89E-04±1.73E-04	2.60E-05±9.37E-06	4.28E-05±1.71E-07
	n	1.4884±0.2533	2.2662±0.0708	2.3377±0.0053
Two-term	R^2	0.9559±0.0162	0.9125±0.0051	0.9117±0.0010
	RMSE	0.0644±0.0176	0.1103±0.0040	0.1128±0.0004
	RSS	0.2938±0.0025	0.3046±0.0221	0.2291±0.0018
	χ^2	0.0049±0.0026	0.0146±0.0011	0.0164±0.0002
	a	0.5485±0.0238	0.6056±0.0027	0.6004±0.0012
	k_1	0.0019±0.0002	0.0115±0.0002	0.0168±0.0001
	b	0.5485±0.0238	0.6056±0.0027	0.6004±0.0012
	k_2	0.0019±0.0002	0.0115±0.0002	0.0168±0.0001
Midilli and others	R^2	0.9980±0.0002	0.9975±0.0003	0.9990±0.0001
	RMSE	0.0137±0.0019	0.0186±0.0010	0.0124±0.0008
	RSS	0.0146±0.0039	0.0087±0.0010	0.0028±0.0004
	χ^2	0.0002±0.0001	0.0005±0.0001	0.0002±0.0000
	a	0.9685±0.0235	0.9778±0.0001	0.9827±0.0031
	k	1.05E-03±1.05E-03	1.87E-05±7.13E-06	3.19E-05±1.73E-06
	n	1.3535±0.4707	2.3246±0.0755	2.3964±0.0065
	b	-1.19E-04±8.14E-05	-7.67E-05±8.06E-07	-6.12E-05±8.26E-06
Peleg	R^2	0.9903±0.0073	0.9534±0.0015	0.9459±0.0013
	RMSE	0.0288±0.0147	0.0806±0.0019	0.0884±0.0012
	RSS	0.0549±0.0283	0.1624±0.0074	0.1405±0.0037
	χ^2	0.0011±0.0009	0.0071±0.0004	0.0088±0.0002
	a	758.9982±24.8027	160.0821±7.5613	103.9862±1.4922
	b	0.3749±0.0715	0.2164±0.0345	0.2747±0.0090
Silva and others	R^2	0.9713±0.0064	0.9591±0.0028	0.9641±0.0015
	RMSE	0.0522±0.0104	0.0755±0.0032	0.0720±0.0014
	RSS	0.2023±0.0301	0.1426±0.0120	0.0933±0.0034
	χ^2	0.0030±0.0012	0.0062±0.0005	0.0058±0.0002
	a	0.0026±0.0005	0.0194±0.0002	0.0296±0.0004
	b	-0.0196±0.0093	-0.0999±0.0012	-0.1292±0.0019

3.3 The effective diffusivity and activation energy

The effective diffusivity coefficient is required in design and optimization of processes which are involved internal moisture movement

(Franco, Perussello, Ellendersen, & Masson, 2017). The effective diffusivities increased depending on temperature and microwave power intensity. Similar increments were found in the studies of D. I. Onwude, N. Hashim, R. B. Janius, N. Nawi, and K. Abdan (2016a), Torki-Harchegani, Ghasemi-Varnamkhasti, Ghanbarian, Sadeghi, and Tohidi (2016), Vega, Uribe, Lemus, and Miranda (2007) and Bal, Kar, Satya, and Naik (2010). The effective moisture diffusivities of avocado-foam were between 0.59 x 10^{-8} to 6.78 x 10^{-8} m^2/s (Table 3.). These values are in the range of effective moisture diffusivity of foods (10^{-11} - 10^{-6} m^2/s) (Olanipekun, Tunde-Akintunde, Oyelade, Adebisi, & Adenaya, 2015). Similar D_{eff} values were observed in the hot-air drying of pumpkin slices (Onwude et al., 2016a), foam mat drying of tomato juice (Kadam & Balasubramanian, 2011) and lime juice (Dehghannya, Pourahmad, Ghanbarzadeh, & Ghaffari, 2019), packed bed and microwave drying of enriched couscous (Yüksel, Oner, Bayram, & Oner, 2018).

Activation energy (E_a) values for food and agricultural products were generally lied ranged in 10.7 and 110 kJ/mol (Chayjan, Kaveh, & Khayati, 2015). E_a values of avocado foam were found as 15.97 kJ/mol and 17.56 W/g for hot-air and microwave drying, respectively. Similar values were obtained in the studies of Dadali et al. (2007) for microwave drying of spinach, Azizpour, Mohebbi, Khodaparast, and Varidi (2014) for convective drying of shrimp foam and Salahi, Mohebbi, and Taghizadeh (2015) for foam-mat drying of cantaloupe. High E_a value indicate that water in food material is bounded more strongly and removal of water driven by sample's structure (Chayjan et al., 2015).

Table 3. Effective moisture diffusivities and activation energy of avocado-foam

Dryer	**Drying Parameter**	**Effective Diffusivity (m^2/s)**	**Activation Energy (E_a)**
Hot-air	60 °C	4.80 x 10^{-8} ±0.23 x 10^{-8}	15.97±4.53 kJ/mol
	70 °C	4.88 x 10^{-8} ±0.49 x 10^{-8}	
	80 °C	6.68 x 10^{-8} ±0.31 x 10^{-8}	
Microwave	120 W	0.59 x 10^{-8} ±0.12 x 10^{-8}	17.56±1.30 W/g
	460 W	4.68 x 10^{-8} ±0.26 x 10^{-8}	
	700 W	6.78 x 10^{-8} ±0.05 x 10^{-8}	

4. Conclusions

Avocado foam was prepared by adding 30 % of egg white to avocado puree and dried with hot-air at 60, 70 and 80 °C and microwave dryers at 120, 460 and 700 W. Increment of drying temperature and microwave power intensity resulted in an increase in drying rate and shorten drying time by faster removal of water from avocado-foam. Furthermore, five thin-layer model were used to determine the best fitting model to describe the drying behavior. Midilli and other model and Silva and other model were found as best with higher values of R^2 and lower values of RMSE, RSS and χ^2. Effective moisture diffusivity values were increased while increasing drying temperature and microwave power intensity. On the other hand, activation energy values were found in agreement within the literature.

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