Master Thesis

Analysis of market and requirements of plasticizers for flexible PVC

-With a focus on Perstorp's non-phthalate plasticizer Pevalen

by

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Preface

This master thesis has been made possible through collaboration with Perstorp Group which has given us a valuable experience of the ongoing work processes at a chemical company. We would like to thank Perstorp and our supervisors there, Linda Zellner and Jenny Klevås, for their support and knowledge throughout the work. We also want to dedicate a thank you to Anders Magnusson who has taught us all valuable background, regarding plasticizers and the PVC market. Thank you to all sales personnel at Perstorp for answering our questions and letting us interview you about your experience with the customers and to the experienced workers at the R&D department at Perstorp for your help guiding us through the laboratory work you have made.

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Lastly, we would like to thank our families and friends for all love and support they have provided us with!

Abstract

Flexible Polyvinyl chloride (PVC) is a plastic material commonly used in today's society and a fundamental material for a lot of sectors. It has advantages over other polymers such as energy-efficient production, flame retardancy, durability and cost-effective. The one important component in flexible PVC that gives it is flexible properties is the plasticizer. The most common plasticizers used are ortho-phthalates. Concerns about some ortho-phthalates toxicity to humans and other living organism has induced a movement away from using ortho-phthalates as a plasticizer.

The chemical company Perstorp AB has developed a non-phthalate plasticizer called Pevalen, which is a general-purpose plasticizer intended for close-to-human applications of flexible PVC. Pevalen has shown to have favorable qualities both for processing and in the final application and has a low toxicity profile.

This thesis work includes the status of the plasticizer market, regional differences between Europe, USA and China and market requirements for the following of close to human flexible PVC applications; coated fabrics, flooring, wall covering, pool liner and food contact material. These requirements have then been compared to internal work and knowledge at Perstorp regarding Pevalen. To find opportunities for the plasticizer to be successful in each segment and identify possible needs to further complement with strengthening technical information and data.

The market analysis showed that the plasticizer market is very price driven and constantly looking for ways to reduce costs. The most used plasticizers are still the ortho-phthalates due to low production cost and high availability. There is a movement away from using ortho-phthalates with DOTP being the most used non-phthalate plasticizer. Use of DOTP is increasing rapidly on the market and considered the main competitor to Pevalen among the non-phthalates.

Europe is at the forefront of moving away from phthalates and are increasingly interested in the environmental impact and the toxicity of plasticizers. The USA focuses on non-phthalates but is not are so much concerned about sustainable and environmentally friendly products. China is still mainly using ortho-phthalates, but DOTP is increasing. Production speed is one of the most important things here since the market is very competitive, so they are willing to try new plasticizers that can increase productivity.

For a new plasticizer to compete on the market, it has been found crucial that either the product reduces cost by performing better during the process, that the plasticizer is more efficient, or thirdly that the plasticizer has valuable properties that reduce the need for expensive additives or specialty plasticizers.

The analyze of the application segments showed that flooring and wall coverings have similar key requirements; low VOC, abrasion resistance, dimensional stability, chemical resistance, fire retardancy and low smoke generation. Their application market is hard to enter due to it being very price concerned as well as having high production rates. For food contact materials, the following key requirements have been found important: high flexibility, cleanability, abrasion resistance, migration resistance and chemical resistance. This market is very regulated

with stringent requirements. Coated fabrics are considered a promising industry for Pevalen since it gives the material a very soft touch, has low toxicity, low VOC, and good UV-stability which are all factors of high importance in this field. The positive aspects of Pevalen positive aspects are highly valuable in this industry.

Perstorp has done quite an extensive research and laboratory work. However, there are a few gaps, such as abrasion resistance, chemical resistance, and dimensional stability linked to the selected applications that can complement this data. It is also important to always compare with relevant benchmark plasticizers when performing a test. Overall, Pevalen has shown good results in the properties that are important for the researched segments but needs to push more on cost reducing properties.

Sammanfattning

Flexibel Polyvinylklorid (PVC) är ett plastmaterial som används mycket i dagens samhälle och är ett essentiellt material för många sektorer. PVC har många fördelar jämfört med andra polymerer såsom energieffektiv produktion, brandhämmande, beständig och kostnadseffektivt. För att PVC ska få sina flexibla egenskaper krävs en mjukgörare. De vanligaste mjukgörare som används är ftalater. Oro för ftalaters toxicitet för människor och andra levande organismer har gjort att man börjat gå ifrån att använda ftalater som mjukgörare.

Kemiföretaget Perstorp AB har utvecklat en icke-ftalatbaserad mjukgörare under produktnamnet Pevalen, som är en mjukgörare avsedd för applikationer av flexibel PVC som kommer i nära kontakt med människor. Pevalen har visat sig ha goda egenskaper både i produktionsdelen och i den slutliga produkten samt har en låg toxicitetsprofil.

Detta examensarbete omfattar marknadens nuvarande status, regionala skillnader mellan Europa, USA och Kina och marknadskrav för följande flexibla PVC-tillämpningar: bestruket tyg, golvbeklädnad, väggbeklädnad, pooldukar och material i kontakt med livsmedel. Dessa krav har sedan jämförts med internt arbete och kunskap på Perstorp gällande Pevalen. Målet har sedan varit att hitta möjligheter för mjukgöraren att lyckas i varje segment och identifiera möjliga behov för att ytterligare komplettera med teknisk information och data.

Marknadsanalysen visade att mjukgörarmarknaden är mycket prisdriven och ständigt söker möjligheter att minska kostnaderna. De mest använda mjukgörana är fortfarande ftalater, mycket på grund av låg produktionskostnad och hög tillgänglighet. Det finns drivkraft att gå ifrån användandet av ftalater och använda icke-ftalater istället. Dioktyltereftalat är den mest använda icke-ftalat mjukgöraren och anses vara den främsta konkurrenten till Pevalen bland icke-ftalater.

Europa driver ett aktivt arbete för att röra sig bort från ftalater och är alltmer intresserade av mjukgörares miljöpåverkan och toxicitet. USA fokuserar på icke-ftalater men är lika intresserade av hållbara och miljövänliga produkter. Kina använder fortfarande huvudsakligen ftalater men DOTP ökar kraftigt. Produktionshastighet är en av de viktigaste parametrarna för den kinesiska marknaden som är väldigt konkurrenskraftig och villiga att prova nya mjukgörare som kan öka produktiviteten.

För att en mjukgörare ska kunna konkurrera på marknaden, har det visat sig avgörande att antingen produkten minskar kostnaderna genom att prestera bättre under processen, att mjukgörare är effektivare, eller att mjukgöraren har värdefulla egenskaper som minskar behovet av dyra tillsatser eller specialmjukgörare.

Analysen av applikationssegmenten visade att golv- och väggbeklädnad har liknande nyckelkrav: låg VOC, nötningsbeständighet, dimensionsstabilitet, kemisk resistens, brandskydd och låg rökutveckling. Deras marknader är svårt att komma in på grund av att det är mycket priskänsliga och har hög produktionstakt. För material som kommer i kontakt med livsmedel har följande nyckelkrav visat sig vara viktiga: hög flexibilitet, renhet, nötningsbeständighet, migrationsbeständighet och kemisk resistens. Denna marknad är mycket reglerad med stränga krav. Bestrukna tyger anses vara en lovande industri för Pevalen eftersom

Pevalen har egenskapen att ge materialet en mycket mjuk känsla, har låg toxicitet, låg VOC, och god UV-stabilitet som alla är faktorer av stor betydelse inom detta område. De positiva aspekterna för Pevalen är mycket värdefulla i denna bransch och det finns möjlighet att konkurrera med hjälp av dessa.

Perstorp har gjort ett ganska omfattande forsknings- och laborationsarbete om Pevalen. Det finns några luckor som nötningsbeständighet, kemisk resistens och dimensionsstabilitet kopplat till de valda applikationsområdena. Det är också viktigt att alltid jämföra med relevanta benchmark-mjukgörare när du utför ett test. Sammantaget har Pevalen visat goda resultat i de egenskaper som visats vara viktiga för de undersökta segmenten, men Perstorp behöver marknadsföra de kostnadsreducerande egenskaperna mera.

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List of abbreviations

Abbreviation	Explanation
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
ATBC	Tributyl 2-acetylcitrate
BBP	Butyl Benzyl Phthalate
CFFA	Chemical Fabrics and Film Association
DBP	Dibutyl Phthalate
DEHA	Dietylhexyl Adipate
DEHP	Diethylhexyl Phthalate
DEHS	Di-2-ethylhexyl sebacate
DIBP	Diisobutyl Phthalate
DIDA	Diisodecyl Adipate
DIDP	Diisodectyl Phthalate
DINA	Diisononyl Adipate
DINCH	Diisononyl Cyclohexanoate Ester
DINP	Diisononyl Phthalate
DOP	Diethylhexyl Phthalate
DOTP	Di-2-etylhexyl Terephthalate
DOZ	Di-2-ethylhexyl Azelate
DPHP	Dipropylheptyl Phthalate
DUIP	Diisoundecyl Phthalate
DUP	Diundecyl Phthalate
E-PVC	Emulsion PVC
ECHA	European Chemical Agency
EFSA	European Food safety Authority
EPA	US Environmental Protection Agency

EPA	US Environmental Protection Agency
FDA	Food and Drug Administration
GHS	Globally Harmonized System of Classification and Labeling of Chemicals
HMW	High Molecular Weight
IAQ	Indoor Air Quality
IARC	International Agency for Research on Cancer
IDB	Isodecyl Benzoate
IMO	International Maritime Organization
INB	Isononyl Benzoate
ISCC	International Sustainability & Carbon Certification
ISO	International Standards Organization
IUPAC	International Union of Pure and Applied Chemistry
LCA	Life Cycle Analysis
LMW	Low Molecular Weight
NFPA	The National Fire Protection Association
NTP	National Toxicology Program
OSHA	Occupational Health and Safety Administration
PETV	Pentaerythritol tetravalerate
PHR	Parts per Hundred Resin
PVC	Poly vinyl chloride
REACH	Registration, Evaluation, Authorization and Restriction
S-PVC	Suspension PVC
SVHC	Substances of very High Concern
TOF	Tris(2-ethylhexyl)phosphat

TOTM	Tri-2-ethylhexyl Trimellitate
TSCA	Toxic Substances Control Act
VCM	Vinyl Chloride Monomer
VOC	Volatile Organic Compound
WA	The Wallcoverings Association

1 Introduction

Flexible Polyvinyl chloride (PVC) is a plastic material commonly used in today's society and a necessity for maintaining the standard of living expected in life today. It is a fundamental material for a lot of sectors such as medical articles, automotive interior, industrial equipment and building materials. Due to its unique properties, PVC has an advantage over other polymers such as energy-efficient production, flame retardant, durable, versatile, chemical resistance and cost-effective [1].

There have been concerns about PVCs toxicity, both concerning additives such as stabilizers containing heavy metals and the release of HCl when degraded or combusted, but also the plasticizers used. The environmental movement towards sustainability has also had complains about the whole plastic market, due to the poor waste management and slow degradation of plastics, leading to building up in nature and fossil raw materials contribution to greenhouse gases [2].

PVC by itself is a rigid material. The one important component in flexible PVC that gives it is flexible properties is the plasticizer. The most common plasticizers used are ortho-phthalates. Concerns about some ortho-phthalates toxicity to humans and other living organism has increased over the recent decades, which has led to bans and restrictions, and a steady movement away from using ortho-phthalates as plasticizer [1].

As ortho-phthalates are being phased out, this has opened for phthalate-free plasticizers to fill the void. These plasticizers are normally referred to as non-phthalates, to distinguish them from phthalates. The chemical company Perstorp AB has a long experience of producing a wide variety of specialty chemicals, including plasticizers [3] and has now developed a non-phthalate plasticizer called Pevalen™, intended for close to human applications of flexible PVC. It is a general-purpose plasticizer that has favorable qualities both for processing and in the final application. Through the years, a lot of research and laboratory work has been conducted, both in collaboration with customers as well as internal development work. As the plasticizer and flexible PVC markets are constantly moving and evolving, there is a need for analysis of the current state regarding requirements, standards and plasticizers used within a selection of targeted close to human applications and compare to what has been done at Perstorp to find opportunities for Pevalen to be successful in each segment.

1.1 Aims

The aim of this thesis work has been to map out market requirements for a selected number of close-to-human flexible PVC applications that Pevalen is targeted towards. The focus has been on the following applications: coated fabrics, flooring, wall covering and food contact materials. The goal is to understand what properties of the finished product that the producers and customers find important, how these properties can be satisfied by choosing the most suited plasticizer for each specific application and, which plasticizers that are currently chosen within each segment. This to identify which properties Perstorp need to focus on making complementary technical information regarding, to increase the possibility for Pevalen to compete with the currently used plasticizers.

1.2 Disposition

This report will begin with explaining the methods used throughout the work. Thereafter, a thorough background regarding the PVC and plasticizer industry will be stated, including technical information regarding Pevalen and its benefits. The following chapter will show the results of a market analysis with a focus on the general plasticizer market as well as the regional differences in Europe, the USA and China. Thereafter an analysis regarding requirements within the chosen application areas will be stated. Lastly, laboratory suggestions will be specified to complement the found gaps in the technical information existing internally at Perstorp.

2 Method

To map out market requirements for the chosen close to human flexible PVC applications, a broad background study of flexible PVC and plasticizers was needed because of the complexity of the industry. This laid the foundation for the thesis and helped in understanding what aspects to consider while producing flexible PVC products. The background includes a segment about PVC and compounding, as plasticizers and PVC go hand in hand. Then a section about plasticizers in general as well as a more thorough part about Pevalen.

Pevalen is aimed for close to human contact applications and therefore focus has been made on a few applications in this area; flooring, wall covering, coated fabric and food contact material. Difference between requirements, standards, and policies in the market regions Europe, US and China have also been acknowledged.

An introduction to plasticizers and flexible PVC was given by Perstorp. This information was then complemented with the research of literature, such as websites, articles, and books. To find out requirements and standards in each chosen focus area of flexible PVC, additional desktop work was done by visiting websites of manufacturers, associations and institutions and by taking interviews with experts. These experts were within different areas of expertise, working with the formulation and material development at companies producing relevant kinds of flexible PVC products such as coated fabrics, flooring, wall covering or PVC compounds.

These experts have been kept confidential and are only referred to by their area of expertise. For example, for flooring, two experts were interviewed. One from a European based flooring company, denoted as the European flooring expert and one from a US based flooring company, denoted as the US flooring expert. The same goes for the rest of the experts.

To outline the internal knowledge of Perstorp employees about Pevalen, sales personnel, and researchers who have developed and worked with Pevalen have been interviewed. Examination of previously made internal studies and laboratory work connected to Pevalen has been made to understand the existing data.

The obtained information has then been summarized for each application area and region. With data from literature supported with statements from the experts. Experts knowledge has been the main source of information at parts where there has been no information found in literature or where the resources contain information that is outdated. Information from Perstorp has then been evaluated against this to find gaps and opportunities for Pevalen.

The research initially had a broad focus on the chosen applications. The coated fabric application was discovered to be one of the most promising applications for Pevalen. As a result of this, the latter part of the research was then narrowed towards only coated fabric for a more in-depth analysis of that application. The laboratory work connected to coated fabric at Perstorp was looked at and compared to found market demands on testing to map out gaps of missing data.

The initial thought was to do laboratory work at Perstorp lab to complement gaps between requirements from the industry and the existing internal knowledge at Perstorp. Due to circumstances with Covid-19, the work has been heavily affected. No laboratory work could be

done at Perstorp, and, instead, only suggestions for future laboratory work has been made. The market research was also slowed down quite a bit because of the rescheduling of interviews.

3 Background

3.1 PVC

Polyvinyl chloride, or PVC, is a polymer used in broad and large scale on the market. It is the second-most produced thermoplastic in the world, after polyethylene. The versatility of the PVC plastic is vast and can be used in many different applications. This due to its unique ability to be integrated with numerous additives, which makes it possible to produce many different kinds of materials, ranging from rigid compounds with low amounts of plasticizer, to highly flexible elastomers containing large amounts of plasticizer [4].

PVC has a number of advantages over other polymeric materials, which is why it is so extensively used:

- Energy-efficient production
- Cost-effective
- Versatile, printable, paintable
- Flame retardant – inherent fire safety
- Easy to convert
- Durable and have a very long lifetime
- Chemically resistant
- Recyclable
- Low use of finite raw material due to the low carbon content compared to other polymeric materials. [2]

3.1.1 Production

PVC is produced from vinyl chloride monomer (VCM), which in turn is produced from chlorine and ethylene. The chlorine usually comes from common salt, NaCl, and the ethylene is usually derived from oil or natural gas but could also be made fossil free from bio-based feedstock. The polymerization process that is used, and the processing conditions will determine the density and molecular weight of the PVC. The molecular weight of the PVC-polymer is defined by relative viscosity in the United States and by the K-value in Europe, where a lower K-value means lower molecular weight. K-values ranges from 50-80 for most commercial PVC applications [1].

3.1.1.1 Suspension PVC

The suspension polymerization of the vinyl chloride monomer is the most common process for PVC production. The vinyl chloride monomer is suspended in droplets in water where the polymerization reaction takes place. The PVC retained from this process is referred to as S-PVC, and it consists of relatively large particles. This process is used for 80% of all PVC applications, and the resin could be used for both rigid and flexible products [1].

3.1.1.2 Emulsion PVC

The second common type of PVC is the emulsion PVC, referred to as E-PVC, which is produced similarly to S-PVC except for that emulsifying agents are used. Usually, one emulsifying agent soluble in water and one soluble in the VCM, which prevents the coalescence of particles and creates a resin with very small grain size. This makes E-PVC well suited for very soft and flexible applications [1].

3.1.2 Compounding of flexible PVC

The PVC resins need to be compounded with auxiliary additives to create the wanted finished product. Depending on the properties required from the end product, different additives will be used in the compound. The amounts of each additive used in a compound are usually referred to as parts per hundred resin (phr). The plasticizer usually stands for the highest phr of the additives in the compound and gives the PVC its flexible properties. Depending on the wanted flexibility in the end product, up to 150 phr of plasticizer could be used [1, 2].

Another highly important additive for PVC is the stabilizer, regardless if it is rigid or flexible. The stabilizer prevents PVC from self-degradation, which creates hydrochloric acid [2]. Other common additives for flexible PVC are stated and explained in table 1 below.

Table 1 Common additives used for flexible PVC applications with the main functions explained [5].

Additive	**Function**
Heat stabilizers	Preventing from heat degradation
Light stabilizers	Preventing from light degradation
Lubricants	Preventing the compound from sticking to surfaces while processing
Biocides	Preventing from microbial growth on the material
Adhesion promoters	Improves adhesion properties for coatings
Antistatics	Reduces the occurrence of static electricity
Plasticizers	Increasing flexibility of PVC. Usually stands for the highest phr of additive in a compound
Pigments	Providing the color
Blowing agents	Creates a chemical foam
Fillers	Decreasing the cost of the compound and improve impact strength
Flame retardants	Decreasing flammability
Viscosity modifiers	Lower the viscosity of the compound and increase storage stability

When compounding with the more porous S-PVC resin, the additives are firstly absorbed into the PVC giving a dry compound. The time it takes to absorb the liquid plasticizer depends on the K-value of the resin as well as which plasticizer is being used. After the absorption, the

mixture goes through a hot mixing step where the compound is fused together at the so-called fusion temperature, which is also depending on the used plasticizer [1].

When having the higher density E-PVC as resin, the additives will not be absorbed and instead a liquid compound, referred to as plastisol, is created. The two types of compounds, S-PVC vs E-PVC, require different processing techniques [2].

3.1.3 Processing of compounded PVC

Processing of S-PVC requires a melt process where the PVC grains gradually lose their original form and the PVC and plasticizer fuses together under the influence of heat and shear. Common processes for converting S-PVC are, for example, extrusion, calendaring and molding, depending on the wanted shape of the finished product. The melt and fusion temperature that is needed is influenced by the plasticizer being used [1].

When processing the E-PVC plastisol, the liquid is usually coated over some sort of substrate like a fabric, paper or glass fiber. After the coating, heat is applied to gel the plastisol to a semi-solid state, which makes it possible to apply next coating layer. After the last layer is applied, all layers are fused together at the fusion temperature, which results in a homogeneous phase between the plasticizer and the PVC on a molecular level. The temperature needed for gelation as well as fusion is dependent on the plasticizer used [1]. During processing, qualities that are important are the viscosity and volatility. Viscosity is important to be able to create a smooth coat, and the volatility is important because fumes of evaporated plasticizer can be created while heating the plastisol [6].

3.1.4 Applications

There are many different applications of flexible PVC. They can be divided into some broader categories such as films & sheets, cables & wires, flooring, tubing & profiles, coated fabrics and plastisol. Figure 1 shows a pie chart over the use of each application area [2].

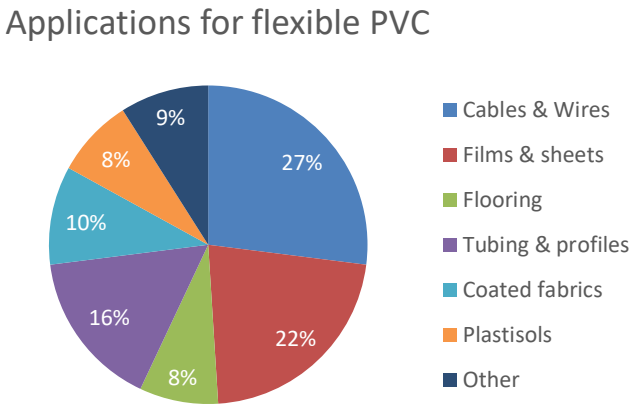


Figure 1 Market shares for different flexible PVC applications [2].

There are varying methods to produce each application. For example, coated fabrics can be made from coating or calendaring.

3.2 Plasticizers

A plasticizer is a substance added to a material to increase flexibility, workability, distensibility and/or softness. The general concept includes any material giving another these properties, such

as water to clay in pottery, but it is most often referred to chemicals used for polymers. About 300 different plasticizers for polymers exist on the market but only around fifty of these are commercially available [7]. Plasticizers have the ability to give a polymer a variety of properties, both during processing and in the finished product. Some of the most common expectations from a plasticizer are listed below [8]:

- Decrease glass transition temperature
- Making material more flexible and softer
- Increase elongation and decrease tensile strength
- Decrease ductility
- Low-temperature properties
- Modification of rheological properties

Several theories of how plasticizers work exist, but none fully describe the plasticizing mechanism alone. Combinations of these theories have given a broader understanding, but there is still insufficient knowledge of why certain plasticizers work better than others. The main concept is that the plasticizer gets incorporated into the polymer matrix without any chemical reactions [9, 7].

For a plasticizer to perform well together with the PVC, it has to have a polar part that binds to the polymer's polar parts and a non-polar part that adds to the free volume. Each kind of plasticizer has its own characteristics and performs differently with the polymer. Within a certain family of plasticizers, such as phthalates, plasticizing behavior is quite similar and often differs between the number of carbon chain number or linearity [7, 9]. The solvency of a plasticizer is the ability to fully solvate into the PVC resin. This is given by a given solubility parameter. The closer the solubility parameter is to the PVC, the easier it will solvate into the matrix. The solvency ability is also linked to fusion and gelation temperature. Higher solvability generates lower temperatures [9].

Plasticizer compatibility is a way of describing how compatible a plasticizer is with the polymer. Compatibility refers to how well the plasticizer conforms with the polymer and related to the solubility and polarity of the plasticizer. The more similar to the polymer the parameters of the plasticizers are, the more compatible it will be [9, 7]. Another important factor is the plasticizer permanence. As the plasticizers are not chemically bound into the PVC matrix, plasticizers have the ability to migrate out of the polymer. It can also be extracted out of the PVC by other chemicals. The volatility of the plasticizer is often considered an indicator of the plasticizer tendencies to leave the matrix [9].

Good processing properties for a plasticizer are plasticizing efficiency, fusion rate, and viscosity [7]. Plasticizer efficiency is a measurement of the plasticizers ability to soften the material. It is often described in hardness versus plasticizer concentration. Plasticizer efficiency decreases with increasing carbon chain number within a family [9]. If a plasticizer is not fulfilling the expected processing quality, additives can be added to correct it, such as fast fusers to increase fusion rate [2, 7, 8].

Plasticizers can either be internal or external. Internals are added during polymerization, called copolymerization, which is a complicated synthesis route and not common commercially. Externals are instead added to a polymer resin, and is a more economical way. It also allows altering formulation to expected criteria to a much higher degree than copolymerization. External plasticizer can be primary or secondary plasticizer, and these can be general-purpose

or specialty. The following sections explains the differences and similarities between each definition [10, 7].

3.2.1 Primary plasticizers

Primary plasticizers directly give the polymer its sought-after qualities in flexibility, workability, distensibility and/or softness. They effectively get incorporated into the polymer matrix and maintain good compatibility over time [9].

3.2.2 Secondary plasticizer

Secondary plasticizers are used to enhance the primary plasticizer since they alone have limited compatibility with the polymer and does not change its characteristics. Secondary plasticizers continue to be used in flexible PVC for their lower cost. They do not have the same mode of softening action as a primary plasticizer but do impart softening behavior when used in combination with a primary plasticizer, although they are used independently in some PVC formulations. Secondary plasticizers are often referred to as extenders [7].

3.2.3 General-purpose plasticizer

General-purpose plasticizers are primary plasticizers that fulfills three criteria's; volume, price and performance, meaning they are produced in an extensive volume to meet market needs, to a competitive price and has a versatile performance. Some plasticizers do have the performance capabilities to be a general-purpose but are produced in small volumes or do not have a competitive price [2].

3.2.4 Specialty plasticizers

Specialty plasticizers are the opposite of general-purpose plasticizers. They are produced in much smaller volumes, are not as versatile, but instead possess certain qualities that make them attractive, such as good electrical or temperature resistance. Specialty-plasticizers can also be quite expensive in comparison with general-purpose plasticizer and are therefore rarely used as the main plasticizer. Specialty plasticizers are usually mixed with a primary plasticizer. The specialty plasticizer is used to enhance the primary and bring certain qualities to the final performance, such as withstanding cold temperatures [2].

3.2.5 Common plasticizers used for flexible PVC

The most common plasticizers for flexible PVC are briefly described below in terms of raw material, properties, and what applications they are generally used in. Plasticizers are frequently referred to by their abbreviations. A very common plasticizer is Diisononyl phthalate, which is abbreviated to DINP [7, 8].

Choice of plasticizer is application-specific; no plasticizer works for every application. General-purpose plasticizers are always the first choice, but some applications require specific performance that cannot be achieved by only a primary plasticizer. There are also regulations that prohibit the usage of some plasticizers in certain applications [2].

When comparing plasticizers, the following requirements and characteristics can be evaluated; softness, abrasion resistance, cold flexibility, fogging, staining, UV-resistance, extraction resistance, lightweight, water abrasion, temperature resistance, flame resistance, dimensionless stability, solvent resistance, outdoor weathering, excretion and emigration resistance [2].

3.2.5.1 Ortho-Phthalates

Ortho-phthalates are phthalic esters produced by esterification of two branched monohydric alcohols and one phthalic anhydride. Ortho-phthalates are often referred to as only phthalates and will be addressed as phthalates. Phthalates are produced commercially from alcohols of C1-C13, but only C4-C13 are suitable for PVC. Phthalates made from alcohols with 4-7 carbon atoms belong to the low molecular weight (LMW) phthalates and phthalates made from 8 more are called high molecular weight (HMW) phthalates. Higher molecular weight phthalates are less compatible with PVC but does not migrate out of the PVC matrix as easily as the LMW phthalates. The HMW phthalates also have a higher boiling point, which gives better high-temperature performance than LWM phthalates [7].

Phthalates used to be the most common plasticizers due to their superior compatibility with PVC, low production costs and high production volumes, making them the standard general-purpose plasticizer. Phthalates are very suitable with PVC because of their plasticizing efficiency, fusion rate and low viscosity [7]. During the past decades, concerns have risen regarding their potential harm to human health, decreasing the usage of ortho-phthalates. Especially low molecular weight ortho-phthalates have been replaced by high molecular weight ortho-phthalates and terephthalates. As a general-purpose group, phthalates can be used in a wide range of PVC applications such as flooring, coated fabrics, wall coverings, medical and more [7, 2].

Some of the most common ortho-phthalates are DEHP/DOP, DBP, BBP, DINP, DIBP, DIDP, DPHP and DUP. Their full names can be seen in the list of abbreviations in the beginning of the report. DOP used to be the most used plasticizer worldwide and is still considered as a benchmark plasticizer in the industry. DINP is the runner up to DOP. It is produced from C9 alcohols and therefore has higher molecular mass than DOP, but less plasticizer efficiency, so more plasticizer is needed to obtain the same softness as with DOP. DIDP and DPHP are both phthalate esters of C10 alcohols. Their higher molecular mass gives them lower volatility and better high-temperature performance than DOP, but less plasticizer efficiency. This is a general concept for phthalates; higher molecular mass gives better high-temperature performance and lower volatility but decreases plasticizing efficiency [7].

3.2.5.2 Linear phthalates

Linear phthalates belong to the ortho-phthalate family but have linear or semi-linear chains instead of branched as the equivalent ester of ortho-phthalate do. These are normally considered to be specialty plasticizers, since they tend to be more expensive. This is because the production of these linear phthalates requires feedstock of high linearity alcohols or further manufacturing step, which increases production cost. Linear phthalates have low volatility, giving them excellent high-temperature resistance and are often used in applications exposed to heat. They are also very common in automotive interiors due to low fogging capability. Common plasticizers are 911P/911PL, containing C9-C11 linear or semi-linear ester chains [7, 10].

3.2.5.3 Terephthalates

Terephthalates are phthalates produced from terephthalic acid. The most common one is di-2-etylhexyl terephthalate, abbreviated to DOTP. DOTP is technically a phthalate, but it has a completely different toxicology profile and is therefore considered safe to use. DOTP has become the new go-to general-purpose plasticizer on the market, due to low production cost

and high availability. It is not as effective and compatible as a plasticizer as DOP and is, therefore, a bit harder to process but has good low-temperature properties and low volatility. It is used for applications such as flooring, wall covering, coated fabric and is also allowed in some food packaging, toys and medical applications [2, 7, 11].

3.2.5.4 Cyclo-hexanoates

Cyclo-hexanoates are hydrogenated ortho-phthalates. This group mainly consists of 1,2-cyclohexanedicarboxylic acid diisononyl, called DINCH, which is the product of hydrogenated DINP. Less compatible and processable than DINP but has many positive properties such as low-temperature flexibility, reduced viscosity of plastisol's and good UV-stability. DINCH is a so-called non-phthalate, and it belongs to the general-purpose group. It is used in flooring, wall coverings, film & sheet, automotive wiring and filming coated fabrics, food packaging (cling wrap), toys and medical applications [2, 7, 12].

3.2.5.5 Benzoates

Benzoates are benzoate esters produced by esterification of benzenic acid with either a monohydric alcohol to produce monobenzoates or a diol for dibenzoates. Benozoates are very compatible with PVC. They have high plasticizing efficiency and permeability. Isononyl benzoate (INB) and isodecyl benzoate (IDB) are monobenzoates with low viscosity, density and low temperature flexibility. However, they are mainly used as secondary plasticizer due to high volatility. They have been used in flooring and wall covering as supplements to lower viscosity, resulting in lowered VOC emission from these products [7]. INB is used for flooring and film & sheet products. IDB is used for flooring, wall covering, adhesive, sealants, inks and waxes [13].

Dibenzoate esters are also often used as secondary plasticizer. They have high viscosity and viscosity build-up, high density and high freezing point. Most used are dipropylene glycol dibenzoate (DPGDB) and diethylene glycol dibenzoate (DEGDB). Often blends of the two are used as well [7]. Dibenzoates are mostly used in flooring [13].

3.2.5.6 Adipates

Adipates are colorless and odorless plasticizers produced by esterification of adipic acid and alcohol. They have two key properties, low viscosity and low-temperature flexibility. The two commonly used adipates are Di-2-ethylhexyl adipate (DEHA) and Diisononyl adipate (DINA). DEHA is the most used adipate. It has good plasticizing efficiency and compatibility. Higher molecular mass adipates have lower plasticizing efficiency, which results in adding more plasticizer to obtain the same effect. This can affect the plastisol positively by lowering the viscosity [7].

DEHA is used for a vast number of applications; flooring, wall coverings, films & sheet, automotive, tubes & hoses, coated fabrics, cling wrap and toys [14]. DINA has higher molecular mass, which increases viscosity compared to DEHA, but decreases volatility. DINA is used in adhesives, sealants, and cling wrap [7, 14].

3.2.5.7 Sebacate and Azelate Esters

Sebacate and azelate esters are produced from linear sebacic and azelaic acids. Just like the adipates, they have low viscosity and good low-temperature properties. These esters are one the more expensive plasticizers on the market and are primarily used in applications that require extreme low-temperature performance. Di-2-ethylhexyl sebacate (DEHS) and di-2-ethylhexyl azelate (DOZ) are the two most widely used [7].

3.2.5.8 Trimellitates

Trimellitates are esters of trimellitic anhydride and C7-C10 alcohol. They possess important qualities such as low volatility, heat ageing resistance, low fogging, low-temperature flexibility and extraction resistance. Trimellitates from linear alcohols can improve these qualities even more. These properties have made trimellitates increasingly popular, but they are however quite expensive. TOTM, TINTM, L79TM and L810TM are the most known esters of this group [7, 15].

Tris-2-ethylhexyl trimellitates (TOTM) is the most common one out of these four. It is used for cables & wires, film & sheet, and is also approved for medical application. TOTM is especially used in automotive since it has low fogging abilities due to its low migration rate [7, 15].

3.2.5.9 Phosphates

Phosphates are esters based on phenol or derivatives of phenol. They have good fire resistance properties and are used a lot for applications with a high demand of good fire qualities. Three different phosphates ester groups exist: triaryl phosphates, alkyl aryl phosphates and alkyl phosphates. Triaryl phosphates have good fire resistance qualities and are mainly used for this purpose. Alkyl aryl phosphates have the advantage of producing very low smoke together with PVC. Alkyl phosphate has low-temperature performance and good compatibility with PVC [7, 16].

3.2.5.10 Citrates

Citrates are esters produced from citric acid and are often bio-based plasticizers. Citrates are considered to be safe plasticizers due to low toxicity profile and are used in a lot of sensitive applications, such as medical, food packaging, pharmaceutical coatings and cosmetics. Tributyl 2-acetylcitrate (ATBC) is the most used citrate for PVC. It is used mainly in food-contact applications, toys and medical applications [7].

3.2.5.11 Polymerics

Polymerics, sometimes called polyester plasticizers, are based on condensation products of diols and diacids. They are normally divided into low, medium and high viscosity plasticizers. They have low volatility and high extraction resistance to nonpolar substrates. Polymerics generally have quite high molecular weight, which can lead to processing difficulties. However, their high polarity decreases plasticizer migration out of PVC matrix. Polymerics are used in films & sheets and food contact applications [7, 2, 17].

3.2.5.12 Epoxidized oils

Epoxidized oils are typically referring to epoxidized soybean oil (ESO/ESBO) or epoxidized linseed oil (ELO/ELSO), but other epoxidized oils exist on the market. ESO and ELO are bio-based and are used as secondary plasticizers. They increase heat stability as a co-stabilizer, reduce plastisol viscosity, and improve flexibility. ESO is used in a variety of applications, whereas ELO is more exclusively used for medical applications [7].

3.2.5.13 Sulfonates - Mesamoll

Sulfonates are phenyl esters based of C14–C17 alkane sulfonic acids. They have good gelation properties and saponification resistance. Mesamoll is a general-purpose plasticizer that belongs to this group. It has good gelation performance, resulting in low processing temperatures and shorter processing time. Good light stability and weathering capabilities [7, 18].

3.2.5.14 Pentaerythritol tetravalerate -Pevalen™

Pentaerythritol tetravalerate (PETV) is a non-phthalate plasticizer made from valeric acid and pentaerythritol. PETV is developed and produced by Perstorp AB under the product name Pevalen. This study is performed based on Pevalen™ using the existing technical information about Pevalen. Therefore a more elaborate background will be presented compared to the other plasticizers. The molecular structure of Pevalen can be seen in figure 2 below.

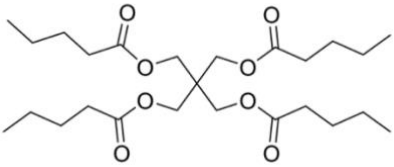
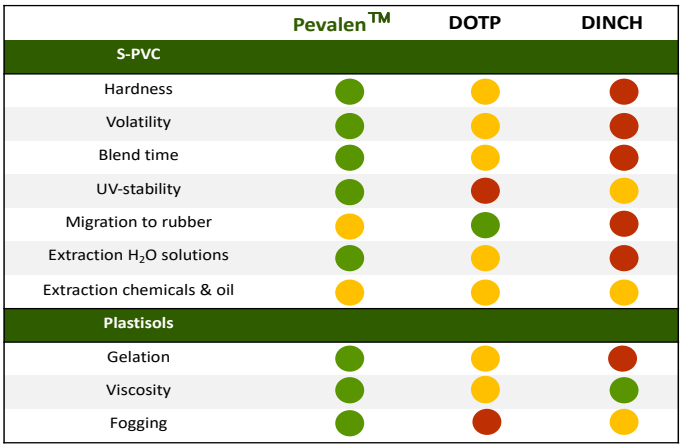


Figure 2 Molecular structure of Pevalen [19].

Pevalen has shown a number of good qualities both for processing, formulating and for the finished product. Some key points can be seen in figure 3 below where Pevalen has been compared with two other non-phthalates, DOTP and DINCH. The color gradations describe the property relative to these three plasticizers.



BASIC FORMULATION WITRH 100 PARTS PVC, 50 PARTS PLASTICIZER, 2 PARTS STABILIZER

Figure 3 Comparison of properties between the three non-phthalate plasticizers Pevalen, DOTP and DINCH in S-PVC and plastisol. The colors, green, yellow and red, describe the properties relative to these three plasticizers. Formulation; PVC 100 phr, Plasticizer 50 phr, stabilizer 2 phr [19].

When processing, Pevalen absorbs very quickly into S-PVC and has a shorter gelation time in E-PVC, as well as a lower gelation temperature than the common non-phthalate plasticizers on the market (figure 4&5). This makes it possible to run the process at lower temperature and have a faster production rate.

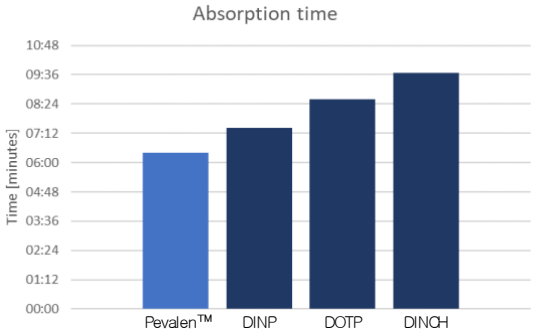


Figure 4 Absorption times compared between Pevalen, DINP, DOTP and DINCH. Absorption time equivalent to ASTM D 2396. Formulation; PVC 100 phr, Plasticizer 50 phr, stabilizer 2 phr [19].

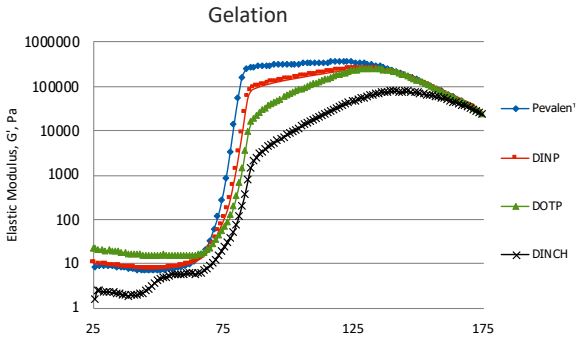


Figure 5 Gelation/Fusion curves for Pevalen, DINP, DOTP and DINCH. Formulation; PVC 100 phr, Plasticizer 50 phr, stabilizer 2 phr [19].

The product advantages Pevalen can give are low volatility (figure 6), good UV-stability (figure 7) and low smoke release while burning. This is mainly due to its aliphatic structure and the absence of an aromatic ring [2].

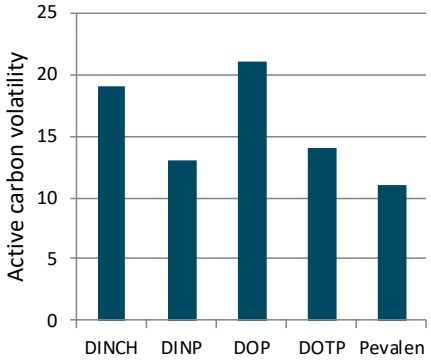


Figure 6 Volatility comparison between DINCH, DINP, DOP, DOTP and Pevalen. Standard ISO 176 Method A, modified at Perstorp. Formulation; Plasticizer 50 phr, PVC 100 Phr, Stabilizer 2 phr [19].

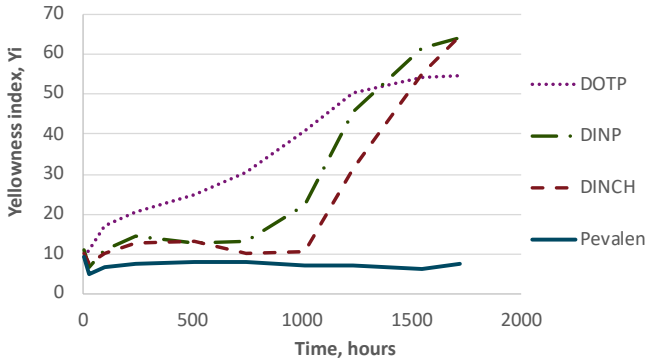


Figure 7 Yellowness index compared between Pevalen, DINCH, DINP and DOTP after time in UV-light. Method; 1716 hour QUV- test to measure yellowness index. QUV lamps 340 A, cycle 4h/60°C + 4h/50°C + UV. Color measured with Dr. Lange. Formulation; Plasticizer 30 phr, PVC 100 phr, Stabilizer 2 phr [19].

The extremely high softness Pevalen brings, gives a big advantage when formulating, since less plasticizer can be added to receive the same softness of the product when compared to other common plasticizers (figure 8). The softness, in combination with the low volatility, gives Pevalen the highest plasticizer efficiency compared to any phthalate or non-phthalate plasticizer on the market today. It is also possible to reduce the amount of UV-stabilizers since the aliphatic structure of Pevalen gives high UV-light stability. [2]

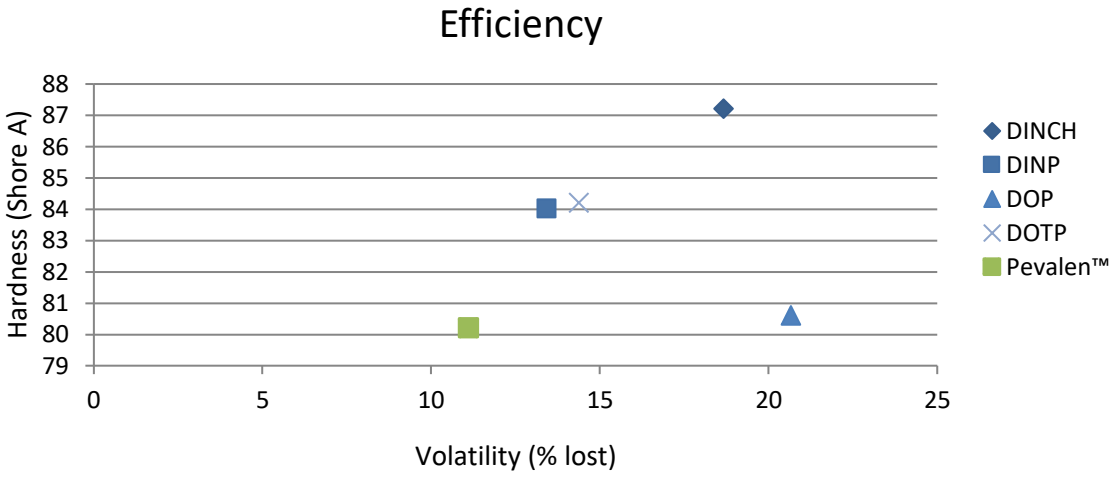


Figure 8 Plasticizer efficiency measured in terms of hardness in comparison with volatility of the plasticizer. Pevalen, DOTP, DOP, DINP and DINCH are compared, showing the significantly best efficiency for Pevalen. Formulation; PVC 100 phr, Plasticizer 50 phr, stabilizer 2 phr [2].

Apart from all these properties, Pevalen has also shown a low toxicity profile as well as being a true non-phthalate. Thanks to this, Pevalen is well suited for close-to-human applications [20].

Pevalen also exists in a bio-attributed version called Pevalen™ Pro, where the same molecule is produced with renewable resources instead of fossil, based on the mass balance concept certified by the ISCC [20].

3.2.6 Summary of plasticizer positive and negative aspect and application area

The properties of a plasticizer generally depend on its molecular weight. The LMW plasticizers have fast gelation and absorption, higher efficiency but also higher volatility, therefor they are preferred in applications where a high production rate is wanted. The HMW plasticizers have slower processing properties and gives less softness but have lower volatility and low extraction

and migration of the plasticizer, which is positive for a product with a wanted long lifetime. There is no plasticizer possessing all properties, therefore, there is always a tradeoff in properties while choosing a plasticizer. It is of high importance to know the end-use requirements of the products to be able to choose the most suited plasticizer for that application [2].

Table 2 below, shows a summary of each plasticizer group's positive and negative aspect to get a good overview of why they are used in some applications and what limitation they have.

Table 2 Positive and negative properties for plasticizers in general as well as common application areas for each plasticizer group [7, 2].

Plasticizer	Positive properties	Negative properties	Application area
Adipates	Good low-temperature performance Low viscosity	Low hydrolytic stability	Plastisol, especially for food cling films
Benzoates	High compatibility with PVC Fast fusion	High viscosity Requires to be mixed with other plasticizers	Flooring
Citrates	Low toxicity Low odor Fast fusion	Fast degradation High cost	Food contact material Medical
Cyclohexanoates (DINCH)	General-purpose potential Non-phthalate Good low-temperature performance	Processing properties Plasticizer efficiency Availability	Close to human applications
Epoxidized oils	Increases heat stability Reduces viscosity Bio-based	Secondary plasticizer	Used in most application areas
Linear phthalates	Good low-temperature performance Great weathering and light stability	Slow processing Phthalate plasticizer	Coated fabrics Automotive Roofing

Ortho-phthalates	Fulfills general-purpose criteria Low price	Toxicity	General purpose
Pevalen (PETV)	High efficiency Fast processing Low processing temperature Low volatility Good light stability Low smoke	Low-temperature performance Few producers	Close to human applications
Phosphates	Great fire retardancy and low smoke generation	High price Low-temperature performance	Most types of applications where fire properties are important
Polymerics	Great extraction resistance and permanence	Slow processing	Food contact and other applications exposed to oil, grease and solvents.
Sebacate and Azelate	Great low-temperature performance Low viscosity	High price	Extreme low-temperature applications
Sulfonates **(Mesamoll)**	High efficiency Fast gelation Non-phthalate	High price Few producers	Close to human applications Food contact
Terephthalates **(DOTP)**	Fulfills general-purpose criteria Non-ortho-phthalate Good low-temperature performance	Processing temperature Varying quality	Close to human applications
Trimellitates	Very low volatility and fogging	Bad UV-stability Plasticizer efficiency	Automotive interior

	Good heat-aging resistance	High price
	Non-phthalate	

3.3 Environmental concern and toxicity

The ortho-phthalate ester DOP, also known as DEHP, used to be the industry standard plasticizer, since it had great plasticizing performance and was cheap to produce. A couple decades ago, concern regarding DOP and a few other LMW phthalates impact on human health, resulted in bans and restrictions in Europe and the state of California and a global movement away from using ortho-phthalates. DOP has instead been replaced with HMW phthalates such as DINP, DIDP, DPHP and linear phthalates. Non-ortho-phthalates has also been increasing, especially DOTP, but ortho-phthalates still represent the majority [7].

A study from 1982 by the National Toxicology Program showed that mice and rats developed liver tumors when feed with high doses of the ortho-phthalate DOP for a year. This lead to the International Agency for Research into Cancer (IARC) listing DOP as "probably carcinogenic to humans". This study ignited extensive research and testing of phthalates globally. Some lower molecular weight phthalates (C4-C6) have been deemed to generate health problems for rats, and in Europe, publications of analyses and risk assessments resulted in labeling some LMW phthalates as carcinogenic, mutagenic, or reproductively-toxic. The HMW phthalates have, however, not been considered to be of the same concern [21].

There has, however, been some questioning if these results on rats and mice is interchangeable with how humans will be affected by exposure. The IARC has withdrawn their listing of DOP as possible cancerogenic due to lack of relevant evidence of phthalates toxicity to humans. Despite this, enough relevant information has been published for the movement to be irreversible [21].

In Europe, the ortho-phthalates DOP, DBP, BBP and DIBP are forbidden in toys for children that can be put in the mouth, and by July 2020 they will be almost completely forbidden to use, with some exceptions [22]. California has with proposition 65 included not only these, but also DINP and DIDP. DINP and DIDP are completely prohibited in some products, and other requires a declaration warning that a product contains these phthalates. DINP and DIDP are still allowed in Europe, and the EU has discharged them from possessing any risk for human health [21].

PVC has also gained public concerns about being harmful to humans. Not only because of phthalates, but PVC previously used harmful additives, such as lead stabilizers and asbestos. A lot has changed in the PVC-industry the last decades and today these substances banned from being used in PVC, but its reputations still remain tarnished. There have additionally been concerns about hydrochloride gas released while production and combustion of PVC, which is a potential toxic and corrosive gas. The PVC and plasticizer industry has unified to address these concerns, and proactively create safer products [2].

Although PVC is a very durable material that can last a very long time, PVC requires separate recycling methods and dedicated equipment that can handle the PVC. The reason is because of the creation of hydrochloric acid, which is causing a lot of corrosion on the equipment. PVC cannot be mixed together with other polymers, since the PVC is not compatible with other

plastics [23]. Concludingly, there is a need for all ingredients to be thoroughly investigated for toxicity and environmental impact for the use of recycled PVC.

4 Results and discussion

The analysis of plasticizers and flexible PVC market has been with a focus on finding out properties and performances wanted from a plasticizer, relevant tests and plasticizers used within each application and region. Information found during desk top work, from articles, book and websites have been utilized and complemented with expert's knowledge as well as statements from Perstorp own employees. Based on this information, gaps and opportunities for Pevalen have been identified and suggested. During research and interviews, a lot of interesting information outside of the main focus has been found and is included in the results.

The market analysis of plasticizers for flexible PVC has been divided into four sections: plasticizer market, regional markets, applications and formulating & processing. The reason for this is that even though there are quite significant differences between each application area in terms of requirements and market structure, there is a lot of corelated information that applies to the whole plasticizer market as well as formulating & processing. These two segments are summarized information that applies to the whole plasticizer industry to avoid repetition and create a base for understanding the plasticizer industry.

The plasticizer market section gives an overall overview of the market drivers, competing plasticizer, environment, and PVC market. The information included in this section is relevant for the whole market. The regional segment gives a more in-depth analysis of Europe, USA and China in terms of what plasticizer is most commonly used and where the market is moving. These regions have been chosen as Perstorp is interested in marketing Pevalen in these three regions and therefore want to know differences between them.

The compounding and processing section include information about the production aspect of flexible PVC, and the application segment includes market analysis of flooring, wall covering, food contact material, pool liner and coated fabric. The last section of coated fabric there is an analysis laboratory work performed at Perstorp on coated fabric. Research about relevant testing parameters has been summarized followed by a suggestion for further laboratory work at Perstorp based on this list.

4.1 Plasticizer market

The market is constantly evolving and adapting to trends, new regulations, and demands in society. Therefore, the literature is sometimes outdated and has not been able take all factors into consideration. This following section will state what experts, working with plasticizers and material development, see as big focal points today. The competing plasticizers on the market will also be discussed in terms on experts' comments of problems as well as positive aspects, this to be able to see what opportunities and threats there are for Pevalen to compete as a general-purpose plasticizer.

When asked about the driving force of the plasticizer market, several of the experts [24, 25] stated that the market is mainly cost-driven, explaining that the choice of plasticizer is primarily based on price. There must also be a sufficient amount of that plasticizer available on the market, preferably several producers, and a guarantee that it can be supplied for the needed

period of time. It is however important that the plasticizer firstly meets the wanted performance, then there is the question about price and availability.

When taking cost, performance and availability in consideration, phthalates remain to be the workhorse plasticizer. They also have known functions and a lot of data available which makes it easier to formulate with them. Pevalen only has two producers at the moment, which means that there are insufficient alternate sources and lack of price competition, leading to uncertainties in supplying the demand. It would therefore be beneficial if other companies or subcontractors started producing Pevalen.

Two experts stated that there is a slow movement away from using ortho-phthalates. The movement mainly has to do with public demand and pushes for prohibitions of phthalates [26, 24]. The regulatory limitation is most likely what drives change in this market. As the market is very price-sensitive, this has held back the switch from phthalates. Experts [26] have stated that it is unlikely for ortho-phthalates to stop being used without an official ban.

Although price is crucial, other aspects are starting to become more valuable, such as having a sustainably produced and non-toxic product. An expert in automotive [27], claimed that already there are requirements for automotive interior to contain a certain percentage of bio-based materials. This is a potential opportunity for Pevalen since it has been shown to have a low toxicity profile.

4.1.1 Competing plasticizers

As mentioned in section 3, there are general-purpose plasticizer, and there are specialty plasticizers. Specialty plasticizers are often more expensive and are therefore more niched into applications where a customer is comfortable with paying more for performance [2]. Pevalen is aimed to be a general-purpose plasticizer and is thereby competing with other general-purpose plasticizers.

There is wide a range of plasticizers available on the market, but only a few are considered to be general-purpose by literature and experts. The ones that have been distinguished as general purpose are DOP, DINP, DIDP, DPHP, DOTP and DINCH. Mesamoll has been mentioned as a potential general-purpose plasticizer but is at the moment not considered to fully fulfill the criteria of cost and volume [28, 2].

DOTP is one of the most used non-phthalate plasticizers as the price is low, production volumes are high, and a lot of producers exist on the market. However, there has been complaints about the compatibility of DOTP, and it is somewhat of an issue. Larger volumes of DOTP is needed to receive the same performance as from DOP. DOTP can also vary in quality, based on producer and raw material, leading to issues with VOC in production and final product [29].

There has also been a lot of discussion about DOTP being a non-phthalate or not. DOTP contains terephthalic acid and is technically a phthalate, but it has a completely different toxicology profile than the ortho-phthalates. One expert that was being interviewed, tells that some costumers have been skeptical of using DOTP, due to it being a phthalate so another truly non-phthalate was used instead [28]. Pevalen could have an advantage here to DOTP, being completely phthalate-free and produced at high quality.

Citrates, trimellitates, linear phthalates, phosphates, adipates and benzoates are used quite a lot, but these cannot compete in the same way due to higher cost or smaller production volumes. There is an increased production of these, but as far as price goes, they might not be able to compete at the moment. They are used more for applications where their specific properties are needed to meet performance requirements [24, 30]. Although Pevalen has shown good properties in comparison with other general-purpose plasticizers it is hard to compete with specialty plasticizers in terms of performance. But on the other hand, prices are often higher for specialty plasticizers [2].

4.1.2 Environmentally friendly and non-toxic plasticizers

The other category Pevalen is considered to have a potential to compete in, is when it comes to the non-toxic and sustainably produced plasticizers as these are aspects, which are becoming more and more important on the market. The climate change awareness has made it profitable for manufacturers to market their products as bio-based or sustainably produced, as this is something that the customers are more and more concerned of [29]. One expert [6] confirms this by stating that a plasticizer with a low carbon footprint, low energy consumption or having a positive LCA, is of high interest in the industry. Bio-based plasticizers, however, makes some people think it is in competition with the food chain, for example, soybean oil. The market is becoming more and more sensitive to these aspects [6].

Several experts [24, 31] have stated that bio-based plasticizers have been asked for by costumers, but the option was turned down when they were presented with the price. However, the commercial building industry, for example, is appealed to use bio-based or non-phthalates since this can give them a green building certificate which adds value to their product [32].

The bio-based plasticizers used today are mainly secondary plasticizers, like the epoxidized oils. Primary bio-based plasticizers however, are interesting to the industry and there is a willingness to try, but due to lack of experience with these products there is need for sufficient data as the cost of trials in the vinyl industry are quite high. According to one expert's experience, most of the vinyl industry are operating with equipment from 50 to 30 years ago and adapting that equipment to a new formulation puts a high demand on the new plasticizer to match very closely to the plasticizer they are currently using [30].

When it comes to bio-based plasticizers, many companies want to be more green, but at the same time, experts in the business are not impressed by the properties and the technical data shown by one of the main bio-based plasticizers, ESO, has compared to the phthalates. Plasticizer efficiency, price, tensile stress, elongation modulus and specific gravity are factors where ESO performs poorly [31]. On top of this ESO also has some toxicity concerns regarding it being toxic to aquatic organisms being bio-accumulative and also causing irritational and asthmatic problems for humans in contact with the PVC [33].

One expert is stating that a citrate plasticizer, which is marketed as a green and healthy alternative is not as non-toxic as it is assumed to be. The hydrolysis resistance is actually lower than of DOP and more chemically sensitive. A phthalate produces two molecules of ethyl hexanol, which could be endocrine disruptor, while hydrolyzed. A citrate will on the other hand produce three of the same molecule [24].

One of Perstorp salespersons in Europe has also noticed changes regarding the environmental movement saying that before the beginning of 2019, the plasticizer market was all about price.

In the beginning of June, it started to change a bit towards sustainability, especially phthalate-free. However, companies are mainly talking about it, but not that many are doing any drastic changes at the moment since it is costly [34].

Since Pevalen™ exists in a bio-attributed version called Pevalen™ Pro, this is a very strong selling point when it comes to sustainability. The molecule is exactly the same as Pevalen, which means that a company could switch between using Pevalen and Pevalen Pro without making any changes [20]. Pevalen and Pevalen Pro does not compete with the food chain when it comes to raw material. Plasticizer producers could benefit from making a life cycle analysis, LCA, to see the full environmental footprint of the plasticizer and use this as a selling point.

4.1.3 PVC market

The PVC market is in general following the overall market for consumption goods. One expert on the plasticizer market says that for the next years, the overall consumption market should grow 1,1%, according to GDP, so the PVC market is predicted to grow almost as much [29].

There has been an ongoing debate of moving away from PVC for about 25 years. But due to the unique properties PVC has such as being inherently fire resistant, low carbon footprint and long lifetime, it has an advantage over other polymers and is still largely consumed worldwide. PVC is also much cheaper compared to other polymers [23]. PVC should therefore be the chosen material when it comes to applications with a long lifetime but avoided for short lifetime products due to the recycling complexity.

The environmental movement to reduce the use of plastic has also influenced the market, but the overall impact has been small. One expert said it might have slowed down the market, but it is not considered a threat. Continuing with saying it is impossible to maintain the quality of life we have today without plastic products as there are so incorporated into our society, so a complete phasing out is unlikely [29].

4.2 Regional

The following segment provides a market analysis of the regional differences between Europe, USA, and China regarding plasticizers consumption and future trends. The flexible PVC market is lightly discussed as well.

4.2.1 Europe

Europe has long been on the forefront of adapting to the environmental and toxicological concerns connected to plasticizer and PVC industry, by providing regulations that limits the use of phthalates and promote the use of sustainable materials instead of fossil-based polymers. The European markets have a very clear goal of going phthalate-free, but the change is slow. The use of DOP is forbidden in the EU, apart from some applications, such as blood bags. DINP, DIDP and DPHP, as well as linear phthalates, are still allowed to be used in close to human contact applications, but due to concerns about phthalate toxicity, the use of these has declined. The market has instead switched into using non-phthalate plasticizers, especially DOTP, which has shown a rapid increase and is expected to continue to grow. DINP is, however, still the most used plasticizer in Europe, followed by DIDP and DOTP. The consumption of each plasticizer group the year of 2017 can be seen in figure 9 [35].

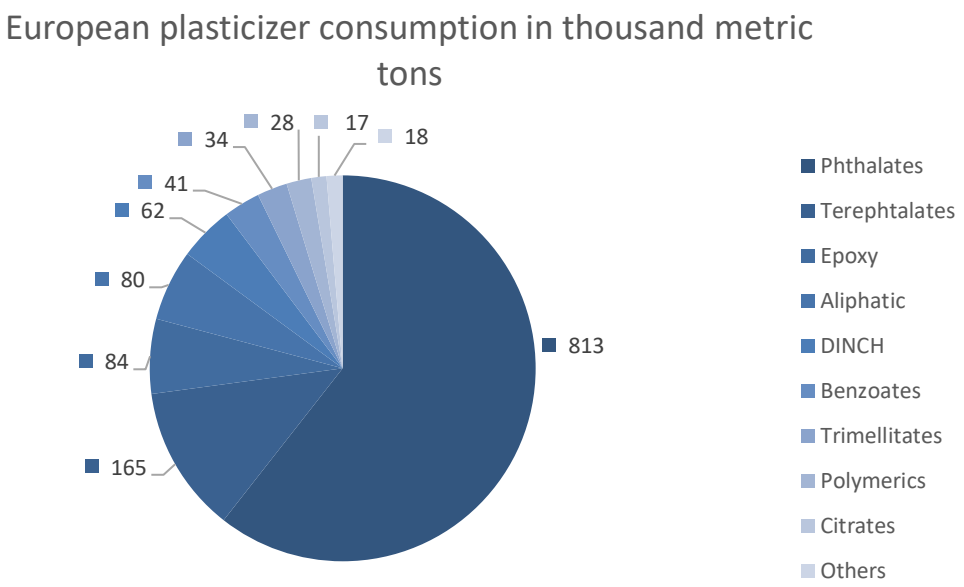


Figure 9 European plasticizer consumption year 2017 in thousand metric tons [35].

The European plasticizer market is not growing and is somewhat oversupplied, so there is instead an internal exchange between plasticizers going on. Production and consumption of plasticizers have even declined in western Europe over the last years. Western Europe is increasingly interested in using bio-based plasticizers and non-phthalates. Eastern Europe, on the other hand, is more price concerned and are therefore mainly using DOTP. Eastern Europe is expected to follow western Europe regarding the use of plasticizers and declining consumption, but with some delay [29, 35].

DOTP is currently the best and most cost-effective plasticizer on the European market. It is not profitable to compete with DOTP prices, so there has been rather a movement into making specialty plasticizers instead. Since the specialty-plasticizer market is more profitable and growing [29, 35]. Sales personnel at Perstorp agrees with DOTP being the biggest competitor on the European market. One saying that for any plasticizer to compete with DOTP, it needs to have more beneficial performance aspects or reduce phr, it cannot compete pricewise [34].

When interviewed, experts stated that Europe has also somewhat started to move away from using PVC. Some south European countries have implemented regulations to reduce the use of halogenated polymers, especially for construction materials such as flooring and wall coverings. This is due to the health concerns of toxic smoke and gases produced when PVC is burning [36, 25].

One opportunity for Pevalen on the European market is the increasing conscious choices from customers to choose phthalate-free, ruling out both ortho- and terephthalates. Pevalen has shown low toxicity in testing and could, therefore, be a safe alternative to switch to. One of the competitors in the non-phthalate group is DINCH, however, one expert in Europe said that DINCH have had problems with availability in the past and poor processing properties, which has led to low market shares. A Salesperson at Perstorp seconds this and states that DINCH used to be the best alternative but is today not growing in market share. He also says that DINCH is considered expensive.

Europe is possibly a good market for Pevalen Pro since sustainability is increasing importance. Pevalen Pro is one of the few sustainably produced general-purpose plasticizers. Perstorp salesperson from Europe [34] said "If a company wants a green product, it might be a chance for Pevalen (Pro) to get that market since there are not many other good green plasticizers competing."

4.2.2 USA

The year of 2003, DOP was added to the list of hazardous substances in California's proposition 65, due to its possible reproductive and carcinogenic effects. A few years later, other phthalates were also added to this list, including DIDP and DINP [35]. If a company sells any product in the state of California, it is mandatory to declare if the material is or is not proposition 65 compliant. To be compliant means that the product is free from any of the substances on the list. This proposition only complies in California, but experts have mentioned that it affects the whole north American market to some extent [31]. There is also some LMW phthalates that are completely banned in certain products, for example toys and childcare articles [35].

Phthalates still represent the majority of plasticizers used in US. DOTP has increased rapidly and is predicted to continue to grow as a result of retailer actions and public sentiments for a complete shift to non-phthalate plasticizers. DINCH is marketed and used primarily for medical and food contact material. There is no production of DINCH in the US, meaning all DINCH on the market is imported. The USA consumption of plasticizers year 2017 can be seen in figure 10 below.

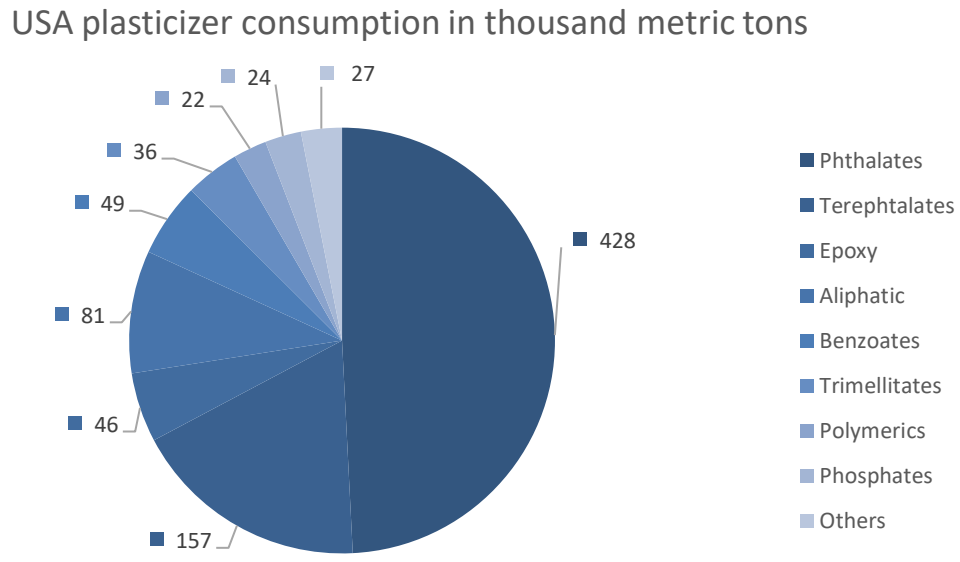


Figure 10 USA plasticizer consumption year 2017 in thousand metric tons [35]

One expert [31] states that the PVC market in USA is expected to grow, and companies producing flexible PVC continue to expand through acquisitions and by building greenfield plants. The business is considered viable and continues to grow in all of North America. He continues by saying that the American market is not as concerned about sustainability as the European, therefor bio-based plasticizers are not as common as in the European market. However, it is starting to gain attention [31].

For Pevalen to compete on the US market or North American, it helps that Pevalen is proposition 65 compliant, so it can be used in California, as well as being a completely phthalate-free plasticizer. DOTP is the most used non-ortho-phthalate' and considered the largest competition. Since DINCH is not used for any other application than medical and food contact, it is not considered that big competitor on the American market, creating an opportunity if consumers ask for completely non-phthalate plasticizers. Pevalen should therefor target this market as a true non-phthalate plasticizer.

4.2.3 China

China is a large producer of both plasticizers and PVC, and the Chinese plasticizer market contains many producers and high production volumes of 3 million metric tons per year. China is also one of the largest exporters, with 3% of domestic production. The year of 2017, DINP represented around 63% of the exported production. China has a very small import of plasticizer and instead of a large domestic production that satisfies the markets plasticizer consumption. The import from Taiwan, Malaysia and South Korea has started to increase due to do lower prices and tax-free policies. The Chinese plasticizer market is set to grow around 5.1% annually until 2022, with ortho-phthalates representing 3.4% [35].

Perstorp salesperson in China [37] says that the plasticizer market in China is aggressive. Big production volumes and high competition make the prices of plasticizers low. He continues by stating that the key aspects are favorable price, performance, and availability. Performance being the largest concern, because good processability is something the customers really tend to focus on. Good processability equals better and faster production rate, although the price is always weighted in the final decision. He also says that the plasticizer consumers in China are constantly trying different plasticizers and testing their performance in their products. Each company has its own standards and production techniques and usually want to test the plasticizers themselves, rather than to rely on results presented to them from the plasticizer company [37].

In the year 2014, China implemented stricter rules regarding environmental impacts from production plants, so companies that could not comply with these had to shut down. Mainly smaller factories, where affected by this, larger companies switched production to DINP and DOTP. DOP production has been on a decline due to decreasing demand, and many companies have switched to producing DOTP and DINP [35].

Several experts say that due to the prohibition of DOP is EU and restriction in the US, Chinese producers looking to export products to the EU and the US cannot use DOP as plasticizer. Perstorp salesperson says that this is also one of the reasons why DOP is declining [37, 26, 29].

Even though production and consumption of DOP have decreased and is expected to do so even more, DOP is still the most produced and consumed plasticizer in China, followed by DINP and DOTP. DOTP and DOP can be produced to such low cost that it is hard for other plasticizers to compete. DOTP is expected to be the non-phthalate that increase the most the following years [35]. China is expected to have nearly doubled its consumption of DOTP by 2024 [38].

Perstorp salesperson has identified that DINP, DOTP and DINCH, including local equivalent UPC UN 899, are the main competition for Pevalen on the Chinese market. The Chinese market does not seem to be moving towards bio-based plasticizers any time soon because of the competitive climate [37]. The Chinese consumption of plasticizer year 2017 can be seen in figure 11 below.

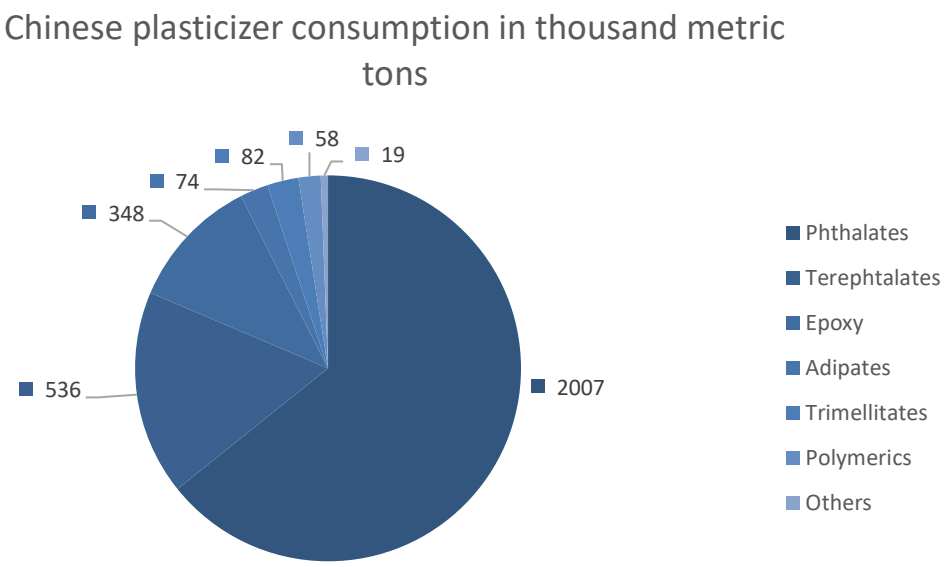


Figure 11 Chinese plasticizer consumption year 2017 in thousand metric tons [35]

Perstorp salesperson in China, says that for Pevalen to compete on the Chinese market, it is hard to do so by being imported and therefore, it needs to be produced there. Hence, it might be an option to start production in China [35]. Since a lot of production plants had to shut down, due to regulation, if Perstorp is looking to produce Pevalen in China, there might be companies and brown field plants available, that could start up production of Pevalen.

Processing abilities of Pevalen are close to DOP, which makes it easier to switch to a plasticizer with similar processing properties. The Chinese market has a very high-speed production pace, needing good processing performance to speed up production. Pevalen fast processing properties could be of high interest in this market and a factor to really emphasize when going into this market.

4.3 Formulating and processing properties

This segment includes information about the compounding processing part of the plasticizer market. It is difficult to find out online what costumers really consider when choosing a plasticizer and what technical information they want to know, therefore the experts have been asked about important factors for production and processing, to get a good picture of the most important aspects. Statements from an expert on what they make decisions on and look for when choosing a plasticizer are the base of this section.

The main approach when choosing a plasticizer is going for a general-purpose that fulfils the wanted requirements to the lowest cost. If the general-purpose plasticizer cannot fulfil the requirements, a specialty plasticizer is usually added to meet the standard. The more of the general purpose that can be added the better, since the specialty plasticizer is usually more expensive. The end-use consumers are looking for the cheapest product on the market and will not pay for something if they can get the equivalent product for less. This affects the choice of ingredients in the formulation, especially plasticizers since they are a big part of the mixture.

Small cost-saving adjustments can, therefore, be of high importance, so there is always a cost tradeoff when compounding. Using a plasticizer with better properties that costs more but

decreases the need for expensive additives versus using a less expensive one but adding more of the expensive additives have to be weighed against each other. A more efficient plasticizer could also be of high interest since cheap fillers could be added, which reduces the overall cost. Having an efficient plasticizer also automatically reduces volatility, because you can use less plasticizer, and it also tends to stay stronger into the resin matrix [24].

Compounders who make formulations for many different applications see a value in having fewer plasticizers that work for many applications instead of a wide range of different plasticizers. Even if one specific plasticizer is more expensive, it might be more cost-effective in the end since the needs of reformulation will be lower, and the cost of the plasticizer will be more beneficial with higher quantities of use [31].

The compatibility is also very important when selecting a plasticizer. Depending on the process, low or high amount of plasticizer will be used. Different grades of PVC also gives a different structure of the resin, and different plasticizers could be more or less compatible with that kind of matrix. It is important that the plasticizer does not exude from the formulation too much or too quickly. This is connected to low boiling point and the compound being quite volatile [28].

Additives also play a huge part in the compounding. Fillers make materials cheaper because they are less expensive than the other components in the formulation, but they also offer processing properties. It can create shear in an extruder, and that shear helps the material process better. Therefore, a plasticizer that has higher efficiency like Pevalen, is beneficial for the customer for these both reasons [31]. One expert added that fillers could, however, lead to issues with brittleness, so it is a balancing act [32].

Another additive that is common are fire retardants. PVC is on its own very inherent to fire, and it is often the plasticizer that decreases this property. Fire retardants are very expensive, and there are also concerns about toxicity. A plasticizer that has good fire-resistant properties is something a manufacturer is willing to pay extra for [24, 26, 32].

4.3.1 Changing plasticizer

When changing or trying a new plasticizer, an expert explains that they make a comparison with their standard plasticizer. First, the article with the new plasticizer is produced in the same condition and quantities as the standard. The differences in production and performance are recorded. If the results are not good enough, they go on and make changes in the formulation. It is important to not have to make to big changes in formulation or in the parameters of the process because then it might be needed to re-start the whole industrialization process [39].

The new formula goes through a process of analysis. Starting on a small scale in the lab and then working Its way to the main process. It is not difficult to do, but it takes time [26]. Material experts working on PVC formulation usually find it beneficial if they are shown data and suggestions on how their formulation should be adjusted in order to get the same properties they used to. For example, if they could use less of a certain product, they should add more of another or use a certain stabilizer. All these propositions make them more willing to try out the product due to that the chemists do not have to start from scratch with the development process. All the time saved is worth money for the company [31].

4.3.2 Discussion

Many companies have old equipment, that is 30 to 50 years old. They are adapted to DOP, which was the most commonly used plasticizer at the time and is less functional with DINP and

DOTP. Therefore, fast fusers are often needed [30]. Since Pevalen already has very fast fusing properties, these expensive additives could be eliminated with Pevalen. This also means that the customer does not need to handle two different materials and two different injection lines. This means that it could be successful in target companies that were using DOP before. DINP and DOTP also need a higher processing temperature compared to Pevalen and DOP. This is a positive factor in terms of energy savings, as well.

It could be important that the plasticizer is compatible with specialty plasticizers and additives when a certain performance is needed. Therefore it could be of interest to test compatibility with some key specialty plasticizers and additives, especially the ones possessing the properties that Pevalen are performing poorer on, for example, low-temperature flexibility.

As specialty plasticizer often are more expensive, if Pevalen could reduce the amount of specialty while maintaining the same properties, this could save costs as well. If a less specialty could be used when mixed with Pevalen than with another general-purpose and still obtain the same standard requirement. That could also be saving costs.

All help with formulation and processing parameters helps because it reduces the time required testing. Therefore, there is a need for summarizing information on formulation and processing to detect common issues and limitations that can be presented to the customer as guidelines. So that they know which components and process settings are more suited while working with Pevalen.

The high softness of Pevalen makes it possible for compounders to add fillers which are both decreasing cost as well as reducing the carbon footprint and making the material more environmentally friendly. These are key points to continue to focus on while presenting Pevalen to customers.

PVC resin producers are very interested in plasticizer availability and development as well. They need to know that their resin works with plasticizers on the market and also be observant of the future trend with the resin and unknown plasticizer [6]. Therefore, they might find it beneficial to work together with Perstorp to develop solutions with Pevalen.

4.4 Applications

This thesis work has been focused on the following close to human applications:

- Flooring
- Wall covering
- Pool liner
- Food contact material
- Coated fabrics

Within each application, qualities and qualifications have been identified to be able to understand what is needed for a plasticizer to succeed. Same rules, regulations and tests may apply to several different applications.

The coated fabric was identified as one of the more promising applications for Pevalen and has therefore been given an in-depth analysis. The technical segment with suggestions of the attribute to test are related to coated fabric and also the analysis of laboratory work done at

Perstorp as well as suggestions are made on coated fabric, but results may be applicable for other applications as well.

4.4.1 Flooring

Floor coverings are one of the largest applications for PVC resins. There are various end-uses such as in buildings for residence, sports, healthcare, hospitality, education, offices and even in vehicles for public transportation. Vinyl flooring is durable, versatile, easy to maintain and has a low cost. This type of floor is used in areas that are exposed to heavy wear or excessive cleaning [40].

Vinyl flooring can be divided into homogenous and heterogeneous. Homogeneous vinyl flooring consists of one layer of PVC, with sometimes a wear layer on top of that. Heterogenous vinyl flooring, on the other hand, consists of several layers. Layer compositions, material, as well as a number of layers, can vary, depending on sought-after end-use performance. There is generally some sort of backing layer, the core layer, print layer and a wear layer on top. Some floorings also have an extra protection layer above the wear layer. This layer can be made from PVC, but a more common alternative is PU, since it is very resilient to abrasion and chemicals [41, 42].

Floor coverings can come in either sheets or tiles, with very basic look and execution to the more luxurious appearance and higher quality. Visual appearance and quality depend on end-use [41, 43].

4.4.1.1 Properties and performance

To evaluate the relevance of different properties in a flooring solution, technical information on datasheets from three different floor producers, Armstrong flooring [44], Tarkett [45] and Altro [46], have been examined. This gives a lead on what types of testing is performed on the finished floor. To justify this, one American and one European flooring expert have also been interviewed to get their opinion on what they consider to be the most important properties and performance parameters to test.

There are a vast number of ASTM and ISO tests and standards specifically developed for flooring, but companies also have their own standards developed for their wanted requirements [32]. Testing of vinyl floor coverings include the following main aspects [47]:

- Abrasion and wear resistance
- UV-resistance
- Dimensional stability
- Solvent/chemical resistance and extraction resistance
- Cleanability
- Low VOC
- Upholding of color and finish
- Slip resistance
- Flame resistance and low smoke generation
- Electrostatic dissipative

When interviewed, the US flooring expert [32] says that there is a big difference between commercial and residential flooring solutions. Residential tend to care more about the visual

aspect than commercial. They are more interested in flooring that mimics wood or stone. It is therefore important that the plasticizer does not defect the print layer and is compatible with other materials used in the layers so that the visual appearance is not affected. The expert continues with saying that in commercial flooring applications, performance is, however, more important than visual. The flooring needs to be very durable. For example, vinyl composite tiles are used in schools and grocery stores because the tiles will last for a very long time [32].

Handbook of polymer testing explains that dimensional stability can have quite a wide meaning, including thermal expansion, shrinkage, softening point and the effect of liquids. However, dimensional stability is often liked to alterations in the floor, such as shrinkage, when exposed to heat [48]. Dimensional stability was detected in every technical datasheet as well, indicating the importance of this parameter. The US flooring expert also confirmed that testing includes dimensional stability and is especially important on the wear layer. The floor needs to stay the same and not shrink with varying temperatures. On the other hand, it is also important that the floor does not swell when being exposed to water and solvents [32].

Abrasion and indentation are also included in every data sheet that was checked. Depending on where the floor will be used, different requirements are put on the durability. The results are often given as "passed", "no damage" or related to a wear class. There is no indication to what classification system it relates to, but European Resilient Flooring Manufacturers' Institute (ERFMI) describes a universal classification system is used to classify a resilient floor based on what usage it can sustain. From the least durable class, attended for light to medium domestic usage to the most durable class of materials, intended for heavy industrial usage [49]. The US flooring expert [32] seconds that wear resistance is very important and that this can be tested with Castor wheel test and ball drop test. He also states that scratch and scrape resistance is important, for both residential and commercial, but for different reasons. For residential applications, it concerns furniture and animals whereas for commercial it is more about foot traffic from people walking on the floor.

Flexibility is only included in one company's technical data sheet, but European flooring expert says testing flexibility is something that is a basic test to perform. The amount of plasticizer affects flexibility, lowers the flexibility temperature. Tested with modulus 100% or torsion test [28]. US flooring expert also states that it is important to know how the plasticizer affect the rigidity of the product and the creep behavior [32].

Upholding of color and finish is also an important property needed in a floor. Both that it could withstand UV-radiation as well as staining. Staining properties are often tested with common household chemicals or cleaners to see if it will damage the flooring [32]. The North American Laminate Flooring Association, NALFA, has developed standards for testing floors. The usual substances a floor will come in contact with and therefore is important to withstand are the following: Distilled water, 50% Ethanol, Household ammonia, 10% Citric acid, Vegetable oil, Coffee, tea, Ketchup, Mustard, 10% Povidone iodine, Black permanent, Wax crayon and Black paste shoe polish. These substances are tested both for staining as well as chemical resistance and extraction [50]. Chemical resistance is included in every technical datasheet, but the results are only given as "good resistance" or "not affected", giving no indication of limits or chemicals tested. Therefore, it is not considered crucial to have all these tested at this point for Pevalen.

US flooring expert says it is important to look at the migration of the plasticizer. If it migrates to the face of the product, it can lead to yellowing or discoloration of the product, and that affect

the visual appearance. If the plasticizer migrates to the back of the flooring, this can damage the glue holding it in place [32].

The European flooring expert highlights the importance of VOC and a good indoor air quality for flooring applications, especially for residential use. The flooring could be coated with a thermoset material, which has no permeability and works as a barrier for the plasticizer and VOC. If this is the case, the VOC and volatility of the plasticizer will not be an issue, but with a top layer of PVC, these are factors of great concern while choosing a plasticizer [28].

The flooring is a building product and must, therefore, meet the standards and requirements for the specific building it will be placed in. Fire properties are an example of standards that depend on the type of building and occupation of the building and what security system it is equipped with. It is highly important that the material lives up to the fire requirements. There are applications that do not need added fire retardants, since the PVC is naturally fire retardant, and there are other where needed to add high amounts of fire and smoke suppressants to be able to meet the building code. Fire retardants and some suppressants are on the higher end of the price scale. A plasticizer that can reduce the need to add these is highly interesting for the market [32].

4.4.1.2 Certifications

There are a number of certifications that are possible to get for a flooring solution. Indoor air quality (IAQ), which is related to VOC, is one of the most important aspects. There are several certifications related to the emission of VOC from flooring products.

FloorScore is one of these certifications. The FloorScore certification shows that the product complies with emission limits. FloorScore qualifies the product for green building schemes including LEED v4, WELL, BREEAM, and CHPS. US flooring expert says that the FloorScore certification is at the moment more popular in the US that Europe at the moment [32]. Other emission certifications are Emission dans la air interior, M1 certification and Blue Angel. Recognized emission standards are CA specification 01350 and ANSI/BIFMA X7.1-2011.

Another standard related to emission is the EN 16516 *Construction Products; Assessment of Release of Dangerous Substances -Determination of Emissions into Indoor Air*, which is the European standard on reference method to determine emission from construction products of a hazardous substance into indoor air.

The Life Cycle Assessment is another type of certification which has become increasingly important, relating to sustainability and concerns regarding the climate effects that a component has during its lifetime. This can be done on a plasticizer and given certification regarding its life cycle. These certifications can then help the manufacturer of floor covering to choose a certain plasticizer since it can result in getting certifications for the finished product and also a building where the product is used can get further certifications [6].

4.4.1.3 Market analysis

In Europe DINP, have become the most used plasticizer for the flooring application, as DOP has been phased out [35]. The European flooring expert seconds that DINP is the mainly used plasticizer for flooring in Europe but says that DOTP is replacing DINP and other phthalates

increasingly [28]. DOTP has good migration resistance which is one of the reasons it is used a lot in flooring [35]. The use of other non-phthalates, such as DINCH, are growing as well [28].

According to the US expert, the non-ortho-phthalate DOTP is the most commonly used in the united states. The flooring industry in the US is trying to move away from using the ortho-phthalates and DINP, and DIDP are generally not used anymore. If they show up in a product nowadays, it is because of recycled streams [32]. This statement is backed up in literature, explaining that the US market has made a strong move for replacing phthalates in vinyl flooring. The year of 2015, stores in the US made a conscious choice to ban the use of any phthalate plasticizers in their flooring products, forcing the manufacturers to change plasticizer. At that moment, DINP was mainly used plasticizer, and replaced with DOTP [35]. The expert continues by saying that DINCH is used for flooring applications in the European market but is not so common in the US [32].

A PVC expert agrees with the experts on what plasticizer are most commonly used and adds that it is also common for flooring producers to blend a general-purpose with a fast fusing plasticizer. This for two reasons, one being increased productivity and the other being reduction of viscosity [6].

US flooring expert states that cost is the number one concern while choosing a plasticizer for a flooring application. The flooring industry is largely a commoditized industry. Cost and processability are the biggest drivers when choosing a plasticizer. Sometimes a plasticizer will be used only because of cost and processing and not because of final performance [32].

When asked about sustainability and bio-based plasticizers, the US flooring expert said that the US is not really moving away from vinyl due to sustainability. Bio-based plasticizers are not commonly asked for either. This has to do with cost, and private persons are not interested in paying more for a green product. A builder who is going for green building credits might be interested in paying more, but it is not so common. He states that Europe cares more about sustainability [32]. The European flooring experts say non-phthalates and even bio-based are increasing in interest, but there is a very strong price pressure on flooring. Even if they say they want bio-based, they are not ready to pay the price [28].

Perstorp salesperson also says that the flooring market in Europe is moving away from phthalates although it might take a few years [34]. In China, the most used plasticizer for flooring is DOTP. The local price is great, and the availability is high, according to Perstorp salesperson in China [37].

US flooring expert claims that the flooring industry seems to be fairly stable at the moment, but the market is changing, however between different PVC products. For example, moving away from carpets but instead increasing in Luxury vinyl tiles [32].

4.4.1.4 Discussion

This is a hard market to enter due to the high pressure on keeping costs down and the production rates up, especially with a plasticizer even slightly more expensive than DOTP and DINP. Few companies seem interested in stopping production from changing the formulation. But at the same time, the high demands on processing properties is an aspect that gives Pevalen an advantage compared to DOTP and DINP. Pevalen has shown good properties in the test made at Perstorp with absorption times, much faster than DINP and DOTP. Faster processing gives

customers the possibility to produce more. There is also the possibility to reduce cost by excluding the fast fusers often used in flooring.

Tests show much lower VOC and volatility for Pevalen in comparison with DOTP and DINP. This gives good arguments for using Pevalen for flooring. Emission is one of the most important aspect for flooring. There are also a lot of certifications related to VOC, such as floor score, Blue Angel.

A gap found in the existing technical data at Perstorp is that when it comes to abrasion, there are very few tests concerning abrasion resistance of Pevalen. However, the existing test showed some indications for good wear resistance properties for Pevalen compared to DOTP and DINCH, although no phthalates have been compared with as a benchmark. If data on positive abrasion and wear resistance for Pevalen compared to both DINP and DOTP could be shown, this gives a good reason for customers to choose Pevalen. There is also need for complementing the data on chemical resistance to common cleaning agents like chlorine Therefore, the suggestion is to do laboratory work on abrasion resistance on PVC sheets, where the common non-phthalates, as well as phthalates, are compared with Pevalen.

Fire retardancy and low smoke release, as well as smoke toxicity, are a key aspect for commercial applications but there is a limitation in the existing data regarding Pevalen. The salesperson at Perstorp mentioned that a customer had conducted tests on Pevalen formulations for public transportation flooring where the demands on the fire and smoke properties were very high where only Pevalen attained to these standards. If Pevalen can prove good fire and smoke properties, this is considered a huge advantage since the fire retarding and smoke suppressing additives are very expensive [24]. With a plasticizer possessing these properties itself, this means that the customer could exclude these expensive additives, or at least add less. Some plasticizers that are good for fire retarding exist on the market, but it is also a price and availability issue connected to these. The proposal is to continue to investigate the fire and smoke properties of Pevalen to be able to show these to customers.

4.4.2 Wall covering

Wall covering is common in both residential and commercial applications. They are used for their durability and easy to maintain as well as the decorative aspect. The décor of wall coverings can be quite versatile, including both print and texture options. There are several different types of wall coverings, but the main concept is a substrate or backing layer, a middle layer and a decorative layer. They can be divided into the following categories [51]:

- Vinyl Coated Paper, which means the backing is paper-based. More common for residential applications.
- Paperbacked vinyl PBV, which also has paper backing but with a thicker layer of vinyl resulting in a more durable and longer-lasting product.
- Fabric Backed Vinyl FBV, which is a fabric backed wall cover. The fabric can be either woven or non-woven.

There are three different types of FBV wall covering. They are differentiated by performance abilities of wear resistance: type 1 is lightweight, type 2 is medium weight, and type 3 is heavyweight. There is also a rigid vinyl sheet wall covering, but this is rigid PVC and does not contain any plasticizer [51].

The wall covering expert claims that the product is generally the same regardless of end-use application area. It might be styled different, have a different design on it, but the backings, the vinyl, the inks used to print the design would typically be the same regardless of application. Plasticizers are mainly used in the vinyl layer but can also be in the plastisol adhesive used to adhere the backing to the vinyl. The vinyl layer is adhered to the backing, giving support to the product. The backing could be a woven fabric or a non-woven fabric [26].

4.4.2.1 Properties and performance

The following properties have been distinguished to be important for wall coverings [51, 26, 2]:

- UV-resistance
- Stain resistance
- Abrasion resistance
- Extraction resistance
- Dimensional stability and curling stability
- Solvent/chemical resistance
- Cleanability
- Mold and mildew resistance
- Low VOC emission
- Color and finish
- Fire resistance
- Elongation and tensile strength

The Wallcoverings Association has created the quality Standard W-101, a standard for Polymer Coated Fabric wall covering. The standard is supposed to give guidance for wall coverings performance and requirements. The standard includes testing for breaking and tear strength, coating adhesion, colorfastness, blocking, crocking, cold crack resistance, heat ageing, shrinkage, stain resistance and cleanability [52].

The wall covering expert mentioned that the wall-covering standard W-101 is an important standard and also refer to CCCW-408D and ASTM F793. Except for the attributes mentioned in W-101, the expert mentions the following aspects to test: chemical extraction (soapy water), fire safety and VOC. The wall covering industry is very concerned about VOC emission. Low phenol is extremely important in the end-use product. California 01350 is an absolute requirement in the US [26].

Two wall covering companies, Koroseal and Vescom, both producing a wide range of PVC wall covers, has VOC emission test done on their products and certifications found on technical sheets and product sites where “Emission de l'air interieur” and “California 01350”. The technical sheets also included one or more fire testing of the following: EN 13501, ASTM E84/NFPA 255, NFPA 101, NFPA 255 and NFPA 286 [53, 54]. The wall covering expert said that fire and smoke testing is really important. ASTM-E84 is a predominant test that the product needs to pass. In large scale rooms, NFPA 286 can be done as a complement to the ASTM-E84 [26].

The wall covering expert says that resistance to microbial attack is of some importance but not an absolute requirement to test, saying that microbial growth and mold are not just for wet environments such as bathrooms and shower rooms, but also regions where it is quite humid. The expert also stresses that the product does not need the absolute ability to resist degradation when attacked by mold and mildew. There are also additives that can be added to the formulation to help. When asked about hydrolytic stability, the expert said it is not commonly tested from an end-product standpoint [26].

The expert continues by saying that other important qualities are conformability, explaining that the wall cover needs to conform to surfaces that are not completely flat and functioning for corners, both inside and outside corner. Cold flexibility as well, but to some degree, as low as -1 C up to around 30 degrees. Adding that the product will probably be exposed to a higher temperature, particularly in transportation and storage, up to 50 degrees, so the permanence at these temperatures is important [26].

The expert continues by saying that printability of the vinyl surface with water-based ink is also very vital. The vinyl needs to have suitable surface energy for it to be able to maintain a good printable surface. It also has to be withstanding a reasonable period of time, adding that the industry standard is six months [26].

When asked about processing performance, the wall covering expert explains that the biggest problems with wall covers happen during processing. Either when fumes from the product, due to the plasticizer volatility, leave the product to a very excessive amount, and gets other parts of equipment and condense on other products, which creates defects. Another issue is oily films. The plasticizer has basically migrated to the surface of the vinyl, creating a surface that makes it difficult to print. It can be prevented to some degree by using corona treatment. He adds that it is the biggest reason for waste and a major issue in the industry [26].

4.4.2.2 Certifications

OEKO-TEX Standard 100 is a certificate given by OEKO-TEX. The certificate indicated that the product is free from any harmful substances [55]. The wall covering expert explained that OEKO-TEX certification of wall covering is quite popular in Europe and that any manufacturers of wall covering in Europe will have their products certified. It is not common in the US and mainly asked by customers in Europe looking to buy from manufacturers in the US. However, European customers are usually fine with the US products not being OEKO-TEX certified [26].

IMO standard certified is the international maritime organization (IMO) fire safety regulations aimed for international commercial ships. The organization's purpose is to increase safety aboard by reducing the risk of fire and aiding emergency responses [56]. The IMO Certification is a fire test for upholstered furniture, but an expert for wall covering says these certifications can be applied for wall coverings as well. He adds that these tests are difficult to pass and involves routinely third-party auditing to make sure the performance of the product stays the same [26].

4.4.2.3 Market analysis

When asked about the market, wall covering expert tells that the industry is very price sensitive. The business is driven by the end-use consumers, and they are very reluctant to pay more for

an equal product. Anything that can be done at a reasonable price to make the products greener, such as bio-based, is always interesting since customers are very green-oriented, but they are not willing to pay the price beyond the standard cost [26].

When it comes to plasticizers used in wall coverings, the expert explains that it is mostly non-phthalates on the market today and will most likely continue to be. There is a strong desire to avoid ortho-phthalates completely in these types of indoor applications. Plasticizers are weighted on price, processing performance and end-use requirements. The environmental and health profile of the plasticizer is important as well as the market is increasingly more interested in these aspects now a day. The expert continues by saying that wall covering manufacturers are not looking to have several different plasticizers in their production. It is much more cost-effective and easily managed to have one plasticizer throughout the whole line of products [26].

The wall covering expert explains that there are many types of plasticizers that would be suitable for wall coverings, but the market will not bear the cost of them. As soon as the minimum requirements are obtained, there is only a question of price beyond that point. Benzoates, adipates, citrates could all be used Instead of phthalates. At least from a health and environmental standpoint as they are less targeted than phthalates [26].

When asked about most used plasticizer, the expert said that the most used plasticizer in the USA is DOTP—adding that DINCH is used by some but has a higher cost. Continuing with saying that DOTP is not used as exclusively in Europe and that in Europe it is the linear phthalate L79, that is the predominantly used plasticizer. The expert inclines that DINP is still used in Europe, but due to health issues related to ortho-phthalates, the pressure is on to move away from them, whereas in the USA, mainly California has a problem with products using DINP and other ortho-phthalates. Ending with saying that DOP is still quite commonly used in China, except for export [26]. The PVC expert seconds that DOTP is the most used in the USA but that in Europe, DINP is most common one [6].

For the future of the market, wall covering expert said that vinyl wall coverings are not common in residential applications in the USA and has been on a decline for the last 20 years but has recovered slightly, because of export to China, Russia and South Korea. In Europe, wall covering for residential is still very prevalent and popular. Commercial wall covering, on the other hand, has been a growing market in the US, and the predominant use of wall covering in the US [26].

4.4.2.4 Discussion

Pevalen opportunities in this area are similar as for flooring since abrasion and impact resistance, low VOC and chemical resistance are of high significance. Both flooring and wall covering are indoor building materials and are expected to not emit any harmful substances above limits. This is gaining more and more attention, as well. VOC emission certification to comply with, such as “Emission de l'air interieur” can help promote Pevalen for applications with high standards. Note that some wall coverings have a covering wear layer that helps with reducing emission, this benefits higher emitting plasticizers, if it prevents VOC from getting out.

Since Pevalen has a favorable toxicity profile, this is something that can be interesting for all indoor applications. Knowing that the plasticizer is not harmful can be a selling point as well

in this industry. The fact that Pevalen is OEKO-TEX compliant is also a very big sales point for PVC wall covering, especially in Europe, where this certification is very common.

The gaps found in the currently existing data regarding Pevalen to be able to be successful in this segment are firstly to complement the technical data on dimensional stability for Pevalen since this has not yet been made. It is also essential to develop the data on chemical resistance based on the common chemicals that the wall could come in contact with. Low migration of plasticizer out of the product or into other layers should be evaluated as well.

Fire retardancy and low smoke from burning materials are vital properties for wall covering. There are a lot of stringent tests, and each application has its own requirement. As mentioned before, Pevalen has shown some good fire properties in testing, which is very positive in this field. This could become a key opportunity if Pevalen alone can show such good results that it lowers the need to add fire retardants.

4.4.3 Pool liner

A pool liner is a sheet of flexible PVC that is used either in installations above ground or buried below ground. The pool liner is usually processed by calendaring or extrusion [41]. The sheet is often colored and textured to be more aesthetically pleasing, sometimes to give the appearance of mosaic or tiles. Pool liners need to maintain visual appearance while withstanding wear from weather, chemicals, and abrasion [57].

4.4.3.1 Properties and performance

The pool liner will be exposed to various threats which could alter its appearance and functionality. The pool liner is expected to be used for a long period of time, so the durability and tensile strength is highly important. Therefore, pool liners are usually made as stiff as possible to be able to perform the high tensile strengths wanted.

Pool liners could also be exposed to temperature fluctuations, which means that depending on the climate it will be used in, it needs to keep the flexibility and not crack, even at cold winter temperatures [41]. It is of importance that the pool liner has good dimensional stability and does not shrink or expand too much, which causes it to wrinkle and stretch [57].

One of the most common reasons to damage and wear on the pool liners is the heavy use of cleaning chemicals like chlorine [41]. One expert seconds this as well and adds that the chemicals used to keep the bacteria down, often start a hydrolyzation reaction of the plasticizer which often lead to a change in color of the material [24].

It is important that the pool liner can withstand the exposure of sunlight over several years and does not change color or degrade. It should not stiffen from plasticizer loss by volatilization or extraction into the water. Weather-resistant biocides are usually added to the compound in a pool liner to prevent microbial growth [41]. An expert is stating that the pool liners need to withstand some biocide tests, however, they are not highly dependent on the plasticizer used, but it still has some impact on it mainly because the plasticizer can hydrolyze and leave a sticky surface which can attract algae [24].

Other aspects the expert stated that was not found in the literature, was the importance of having a material that the ink sticks very strongly on. So some plasticizers that are very oily would reduce the surface tension to do the printing. Secondly, the dielectric or radio-frequency sealing

capability is also of importance. The plasticizers used in the formulation will have an impact on how well the material can be sealed and welded together [24].

CFFA has developed standards for testing and recommended minimum performance requirements from a pool liner. Relevant testing included in this standard are the following: accelerated light ageing, dimensional stability, elongation at break, uniformity, modulus, print abrasion resistance, tear resistance, tensile strength, volatility, snapback (shrinkage), low-temperature impact, mildew resistance, pink stain, soapy water extraction. The standard gives a recommendation of test procedures and minimum performance [57].

4.4.3.2 Market analysis

The literature describes that the plasticizers suited for pool liners are the higher molecular phthalates like DUP, linear phthalates and DOTP [35]. Although one expert state that DPHP is the most common plasticizer used for pool liners, at least in North America [24]. Adipates are usually avoided due to bad hydrolytic stability. Trimellitates are not used either because they have a low resistance to UV-light [41].

4.4.3.3 Discussion

Since Pevalen has shown great UV-stability, the pool liner is an application that is possibly successful due to this. Pevalen also show good extraction resistance to water which is a positive aspect to promote when it comes to pool liners.

The gaps found in the data is that the dimensional stability has not been thoroughly tested by Perstorp, and this is an essential factor to be successful in this field. It is also important to do testing on chlorine extraction so therefor; a suggestion is to do testing on this in comparison with the commonly used plasticizers in this field.

4.4.4 Food contact material

Food contact material concerns any material that could come in contact with food during production or packaging. Flexible PVC application for production includes tubes, hoses, conveyor belts, films and sheets. It is not so commonly used for packaging. The main application for packaging is cling film. Flexible PVC is used for its abilities to maintain flexibility at low temperatures and strong tear resistance [58].

In the EU, these materials must follow EU regulations, including good manufacturing practices. These regulations are maintained by the European Food Safety Authority (EFSA). The regulations include migration testing to make sure that chemicals do not migrate into the food, making it unsafe, changing the composition in an unacceptable way or undesirably taste or flavor [59]. In the US, the Food and Drugs Administration (FDA) is in charge of these regulations. Companies apply for each product they want to have an FDA compliance approval on [31].

4.4.4.1 Properties and performance

The food expert said that for food application materials, the first step is to map out what the material will come in contact with, such as substances or other materials. The material needs to be able to be in contact with the food, which can be oily for example, then there might be a hot or cold step, going into an oven or a freezer and the material will also be cleaned, often with

chlorine or steaming water. This is mostly for tubes, hoses and conveyor belts. For films and sheets, this can apply too, but they can also be hanging in doorways or in front of packaged food in supermarkets [60].

The food expert exclaims that PVC has several great qualities that are applicable in this industry. It is resistant to chlorine, which is a very common cleaning substance in the food industry. It can withstand hot water, which is also a very common cleaning procedure. But the most favorable aspect is the price. PVC is a very inexpensive material, especially in comparison with cross-linked urethanes. Continuing with saying that the biggest issue with PVC conveyor belts is that it wears out faster than urethane, and they have to be replaced more often. Increasing flexibility and abrasion is something the food industry is looking for right now when it comes to PVC for conveyor belts. A conveyor belt that lasts longer and is more abrasion resistant, especially if it is PVC since it is cheaper than PU, would be a very desirable product [60].

4.4.4.2 Certifications

BRC certification is an accreditation that the whole food production chain assures safety and quality. It is internationally recognized. The food contact material expert adds that it covers the most aspects of food production and a lot of big food producers are BRC certified [60].

In the US, a product in contact with food can get FDA approval, and in the EU, it requires ESFA approval. National Science Foundation (NSF) is an American group for equipment manufacture, and they have developed standards and certifications for these kinds of equipment in contact with victuals. NSF 51 is a certification for materials used in food equipment, and NSF 61 is a certification for material that comes in contact with drinking water. NFS 51 is for food equipment material, such as plastic materials, tubing, sealants, gaskets, valves etc. aimed to be used in equipment and applications that will be in contact with food. The compounding expert explained that conveyor belts are food equipment that would fall under the NSF Standard 51 compliance [31].

The expert says that it is not the same as an FDA approval, for the FDA compliance, there needs to be a certain level of production capabilities, and the FDA have been able to come in and audit them. It is very application-specific if there needs to be an FDA approval or not. Also adding that every formulation needs its own NSF certification, every single color has to be listed separately [31].

4.4.4.3 Market analysis

PVC expert claims that the food industry is complicated to enter, due to many specific migration tests [6]. There are stringent regulations regarding food contact material, and PVC has been under a lot of scrutinizes due to phthalates.

The food expert explains that there is quite a big difference between Europe and the US when it comes to regulations. In the EU, it is quite clear what regulations there are to comply with. In the US, the regulations at the FDA can be quite different [23].

The expert continues by saying that for China, the situation is more or less like in the EU because the Chinese government has modelled their food contact regulations from the

European. Estimating that regulations for food contact in China, are 99.9% the same as in the European Union [23].

The expert also explains that in the US, if there is no listed migration limit for a certain chemical or solution, then the material is free to use. There are also substances that the FDA has forbidden which are allowed in the European Union and vice versa [23].

The adipate DEHA and citrate ATBC are the most commonly used plasticizers for cling wrap, as they are considered safe for humans' health. Polymerics and DINCH are also quite used in this application [58].

4.4.4.4 Discussion

Pevalen has shown to have a favorable toxicity profile which is positive for this industry. EFSA approval is currently being done, and there is already an FDA approval.

Since Pevalen has shown good resistance to different fatty compounds, for example, olive oil and n-heptane, this makes it possible for Pevalen to be well suited to be used in applications in contact with greasy products. Therefore, companies producing these kinds of products could be targeted by Perstorp.

Some gaps that have been found in the existing technical data are tests on chemical resistance to cleaning products and steaming water, to make sure the product can withstand the heavy cleaning procedures. Also, if Pevalen would show good abrasion resistance and flexibility, this is beneficial as well since it means the product will be long lasting, which is a crucial point in this area.

4.4.5 Coated fabrics

Coated fabrics are basically fabric backings, that can be woven or non-woven, covered or submerged in flexible PVC. The flexible PVC layer provides wear-resistance, and the fabric gives most of the strength and tear resistance [41]. Coated fabric is a large segment containing many end-use applications, each with different requirements of the performance. It is for example used for upholstery, in automotive interior, tarpaulins, clothing & accessories. Coated fabrics are both versatile and durable. They can be used as thick sheets for tarpaulins covering trucks or as faux letter on luxury handbags. When it comes to performance requirements, it needs to withstand daily wear and tear such as abrasion, staining, UV-light and chemicals. The coated fabric used in public spaces is very often expected to be fire resistant and cleanable as well [24].

When it comes to the production of coated fabric, calendaring is an efficient production method with a fast production rate. The PVC, plasticizer and other ingredients are heated, for example in an extruder, and followingly pressed out between sequential pairs of heated calendaring rolls to form a film or a sheet. The calendared film is combined with a textile backing either directly as it leaves the calendar or in a lamination step later on. Coated fabrics could also be produced by a coating process where a plastisol is used. The textile is coated with a PVC foam layer and then fused together with a non-foamable plastisol protective wear layer in an oven [61]. PVC formulations for coated fabric contain plasticizer in the ranges of 60-85 phr [5].

4.4.5.1 Market analysis

North American coated fabric expert says that the most common plasticizer in coated PVC fabrics is DPHP, typically blended with DIDP or DINP. Adding that DINP is not so common anymore due to concerns regarding toxicity [24]. The European coated fabric expert says that DIDP, DPHP, DUP are normally used for coated fabric, but DINP and DOTP are commonly used as well [30].

Perstorp salesperson in East Europe said that the general-purpose plasticizers used in the coated fabric industry used to be DINP and DPHP, but due to the big concerns regarding phthalates the use of DOTP has taken market shares from DINP and DPHP. Although, it has shown that DOTP is not performing as well as the ortho-phthalates in the end product, where migration of the plasticizer has been a major concern, especially into oily substrates. But some producers still choose to use DOTP due to the low price and great availability on the market. This most strongly applies to markets with high price-pressure, like eastern Europe [62].

The overall trend for this application segment is that coated fabrics and artificial leathers are predicted to increase the following years. This due to the growing public awareness regarding sustainability. With this in mind, consumers value the use of renewable raw material and products produced through less energy-demanding processes. The consumers also increasingly consider the ethical aspect of using animal-based leather products and prefer artificial leather instead. The lower price of artificial leather compared to animal-based is also a benefit for the growth within these applications [63].

4.4.5.2 Certifications

OEKO-TEX Standard 100 is a certificate given by OEKO-TEX that applies all textiles as well as PVC coated fabrics. The certificate indicates that the product is free from any harmful substances and therefore beneficial to get on a finished product. The fact that Pevalen is OEKO-TEX compatible makes it possible to receive an OEKO-TEX certification on the product [55].

4.4.5.3 End-use applications

Due to the different end-use applications and requirements of those, this section has been divided into subsegments. Each segment will be describing more in detail what aspects and properties are considered important and the current status of that market. This section has been divided into the following subsegments: i) Automotive interior; ii) Clothing, accessories & footwear; iii) Marine; iv) Outdoor and v) Indoor.

4.4.5.3.1 Automotive interior

Flexible PVC coated fabrics are used for various applications in the automotive industry, for example, instrument panel skins, seat upholstery, door panels and trim parts. Using polymeric materials reduces the weight of the car, resulting in a more energy-efficient car, which is a focal point of the industry. Especially with the new electric cars with batteries, since they weigh considerably more than the combustion engine [64]. There are also applications using foamed PVC, which have a cushioning effect. This is of importance not only due to appearance but also because of the reduction of noise from the engine and outside [27].

4.4.5.3.1.1 Properties and performance

All automotive companies have their own specific standards and specifications. Therefore it is difficult to make a general description of this area as it differs so much from one company to another. While talking to the automotive expert, it was also stated that different demands and requirements of the material are related to each part of the car as well as the climate the car is designed for. If the car is designed for hot climates with a lot of sunshine, the material used will need to withstand these temperatures and levels of UV-radiation as well as cars used in cold climates will require to withstand the winter temperatures. There could also be differences in requirements depending on the price range of the car. A high-cost car would be using a premium quality artificial leather while a low-cost car would use a more cost-effective material [27].

When it comes to properties of importance within this application, literature states that one of the main concerns is that the plasticizer evaporates from the material which creates a film on the inside of the windshield that limits the visibility for the driver. Hence, very low volatility, fogging, and VOC is important, especially for applications located close to the windshield. Shape, color and finish of the coated fabric are important to achieve the cars design expectation. It is also essential to meet specifications for low flammability, abrasion and flexibility [41]. One expert is confirming the high importance of all these aspects but apart from this, also adds the importance of stain resistance and resistance to different cleaners and water, since most people like to have a clean car. Continuingly, people commonly are using lotions and sunscreen. Exposure to mineral oils and solvents used in these products are, therefore, inevitable [30].

The expert states that most of the testing in the automotive industry is made by the tier1 and tier2 suppliers who are producing the parts, but they work closely together in contact with the automotive company and their standards and every material in any part needs to be certified [27].

4.4.5.3.1.2 Market analysis

The literature describes that the most commonly used plasticizers in the automotive industry are trimellitates, linear phthalates and polymerics due to their low volatility and low fogging [41]. When experts were asked about most commonly used plasticizers one said that depending on region and part of the car but that DINP, DOTP and DOP are used as general-purpose [27]. Another one claimed that automotive industry often uses DIDP or DPHP as plasticizer [30]. The automotive expert explained that, depending on performance requirements, linear phthalates, as 8-10L or 9-11L, are also quite commonly used. Even up to C11 and C13 are used when the requirements are very stringent [65].

One expert is saying that the automotive industry currently is moving in two segments very significantly. Firstly, towards non-phthalate plasticizers but at the same time, they are also focusing on bio-based plasticizers. The automotive sector would like to make sure they are environmentally friendly as possible in all parts of the car. Therefore, it is usually very encouraging to present a bio-plasticizer to them, and if it is cost-effective, they will be highly officiated and try to implement it [30]. Although, another automotive expert says that a bio-plasticizer often have a higher cost than the regular, currently available plasticizers. In this case, it could be a possibility to use these products in a premium leather seat, but not in a leather seat for a low-cost car [27].

The automotive expert also highlights the importance of a secure supply chain that will be able to deliver the material needed the following 10-15 years. The testing and certification procedure for each car model in the industry is highly costly and being forced to make a new material due to availability issues of the original The use of polymeric materials like flexible PVC in cars is increasing due to already mentioned lightweight properties, but the automotive industry, in general, have been on a decline [27].

4.4.5.3.1.3 Discussion

Pevalen has shown results in low volatility and could, therefore, have a great potential in the automotive industry. The results do not quite live up to the levels of TOTM, but on the same time since TOTM has shown rather poor UV-stability [41], this gives Pevalen an advantage compared to TOTM, especially for cars aimed for sunny climates.

A gap found in the existing data are results on abrasion resistance for Pevalen which is highly important for this application. There has neither been much work done on stain resistance. Tests on migration to other plastics have been carried out but there is a gap in the existing data when it comes to PU. A suggestion for future laboratory testing would therefore be a migration test to PU, since many parts in a car lies in contact with PU and it is important that the materials do not loose properties in the connecting surfaces.

4.4.5.3.2 Clothing, accessories and footwear

Coated fabric can be used for raincoats, shoes, bags, pants, and jackets. Shoes can, for example, be walking boots or rain boots. As this segment is quite large and covers a lot of different end-use applications, their requirements can differ. A lot of applications are for rougher weather such as raincoats and boots and require withstanding water and cold temperature. Other applications such as jackets and handbags might not be exposed to the same harsh weathering. Faux leather made from flexible PVC, is used a lot for clothing and accessories, such as bags, shoes, pants and jackets. The feel and appearance of faux leather are very important. It is preferred to mimic real leather as much as possible.

4.4.5.3.2.1 Properties and performance

Both performance and appearance are important, as the appearance is often what costumers go for when buying a product, but a certain level of performance is often expected. When it comes to performance, the following aspects are considered important: VOC, abrasion resistance, UV-light resistance, staining, color bleed, smell, and chemical resistance. To what extent depends on the kind of environment the product will be used in. One expert adds that clothing and accessories intended for harsh weather such as rain and snow need to be very resistant to weathering and cold temperatures. It is important that the fabric does not crack when it gets cold and migration can also be an issue since the fabrics could be in contact with other plastic materials, one example of this is ski boots [39]. Flexible PVC in shoes also require very good resistance to cut growth and flex fatigue [41].

4.4.5.3.2.2 Discussion

Pevalen has good VOC and UV-stability which are important factors in this segment. Pevalen also gives the fabric a very soft touch according to both Perstorp employees and clients who have tried it. This ability will work in favor of Pevalen for customers who are looking for a

material that gives a nice and realistic appearance, especially for faux leather especially if the fabric is for a more high-end product where producers are not choosing plasticizers only of price.

There need to be testing on abrasion and staining, and maybe some migration when in contact with other materials.

Perstorp employee says that in Europe, EFSA certification of often asked for by fashion producers. Since the products are used in close contact with humans, having EFSA approval shows that the product is non-toxic [34]. This EFSA approval on Pevalen is currently being worked on, but there are already result that Pevalen has a low toxicological profile.

4.4.5.3.3 Marine applications

For marine applications, PVC coated fabrics are used in, for example, upholstery, canopies, and coverings.

4.4.5.3.3.1 Properties and performance

A European coated fabric expert explains that products used in marine applications heavily exposed to weather and moisture, which makes resistance to UV-light and hydrolysis very important for the material, as well as the anti-microbial properties. The surfaces need to be easy to clean as well due to the high exposure of dirt, wherefore the cleanability is also of great importance [39].

Chemical Fabrics and Film Association, CFFA, has developed standards for minimum requirements for PVC coated fabrics used for marine upholstery, where test methods and limits are described for the relevant properties of the material. Testing includes abrasion, accelerated light ageing, adhesion of the coating, blocking, cold crack resistance, crocking, flex resistance, hydrolytic stability, mildew resistance, pink stain, scrubbability, seam strength, tearing strength, tensile strength and volatility [66].

The European Parliament has also developed a directive for marine equipment where standards and technical specifications are set for marine equipment used on EU flagged ships. This to ensure marine safety onboard ships and to prevent marine pollution. Therefore, all material, including coated fabrics to be used on an EU ship needs to be IMO-MED certified. IMO standard certified is the international maritime organization (IMO) fire safety regulations aimed for international commercial ships. The organizations purpose is to increase safety aboard by reducing the risk of fire and aiding emergency responses [56].

4.4.5.3.3.2 Market analysis

Coated fabric expert from Europe says that DOTP and DPHP are often used as plasticizers for marine applications. Plasticizers with low hydraulic stability, such as adipates, are not acceptable. Even plasticizers like TOF and other phosphates that are prone to hydrolysis are also often avoided, especially for products designed for warmer climate [30].

4.4.5.3.3.3 Discussion

Pevalen has good UV-stability and flexibility and low volatility. The main issue here is the hydrolytic stability, and if Pevalen manages to show good hydrolytic stability, this application can be viable. Mildew and bacterial growth have not been tested, and this information might be good to know, as well.

4.4.5.3.4 Outdoor applications

Outdoor applications include furniture, covers, tarpaulins, sunshades and tents or any other product that is intended for outdoor usage.

4.4.5.3.4.1 Properties and performance

Outdoor applications can be exposed to sunlight, rain, moisture, soil, dirt, heat and cold. A coated fabrics resistance to weathering is a key aspect for outdoor applications [24]. The weather that a fabric is exposed to varies depending on regional and topographical location. A coated fabric that works well in northern Europe might not be suitable for the southern USA [27].

Bacterial and fungus growth are also important aspects of outdoor applications as well as the cleanability [39]. VOC is less off an issue compared to indoor applications, but for contained spaces such as tents and furniture covers, it might possess a problem with smell. The VOC compounds are diluted enough outdoors to not be hazardous in the same way as indoors [23].

4.4.5.3.4.2 Discussion

Various weathering tests have been made at Perstorp, showing good results for Pevalen, which are positive salespoints in this industry. Moisture and mildew resistance could be tested to complement.

4.4.5.3.5 Indoor applications

This category includes both public and residential applications such as upholstery, tablecloths, sunblind, curtains, mattress covers etc. Upholstery is a very common application for coated fabric, both for residential and commercial. In commercial, it is used in hospitals, public transportation, hospitality and restaurants. Upholstery for furniture in hospitals includes waiting rooms, hospital beds, examination chairs and beds.

4.4.5.3.5.1 Properties and performance

Appearance and feel are important aspects of upholstery intended for residential use. A sofa should look appealing and feel soft to the touch. Abrasion resistance is very important, especially for public applications. Cleanability and chemical resistance as well. Appearance and feel are less important in public furniture compared to residential. Fire retardancy and smoke toxicity are a crucial aspect of public coated fabrics. The slower a material burns, the more time to evacuate and limit the damage as well as not a lot of dangerous and toxic smoke [24].

Chemical Fabrics and Film Association, CFFA, has developed standards for minimum requirements for PVC coated fabrics used for upholstery for indoor applications, where test

methods and limits are described for the relevant properties of the material. Testing includes abrasion, accelerated light ageing, adhesion of the coating, blocking, cold crack resistance, crocking, flex resistance, seam strength, tearing strength, tensile strength, and volatility [67]. One European coated fabrics expert added that the fabric needs to be easy to clean and be resistant to bacterial or fungus growth [39]. Smell and VOC important for all indoor applications [39, 24].

Coated fabrics intended for the medical field are extensively cleaned and disinfected. The fabric needs to withstand chemical exposure. Usually, those designs have an extra protective layer, where the top layer is designed to have less extractable plasticizers. Exposure to soapy water, alcohol-based cleaners, cleaners that are iodine or chlorine-based and quaternary ammonium are examples of cleaners that are used in hospitals [30]. Non-cytotoxicity and antibacterial properties are also important for medical [39].

When talking about wanted properties and performance, North American coated fabric expert explained that abrasion resistance is very important, especially for public applications. Cleanability and chemical resistance as well. Appearance and feel are important aspects for upholstery intended for residential use and less important in public furniture [24]. He also mentions that fire retardancy and smoke toxicity are crucial aspect of public coated fabrics. The slower a material burns, the more time to evacuate and limit damage as well as not a lot of dangerous and toxic smoke [24].

European coated fabric expert also gave insight to coated fabric medical field, explaining that fabric intended for the medical field are extensively cleaned and disinfected. The fabric needs to withstand chemical exposure. Usually, those designs have an extra protective layer, where the top layer is designed to have less extractable plasticizers. Exposure to soapy water, alcohol-based cleaners, cleaners that are iodine or chlorine-based and quaternary ammonium are examples of cleaners that are used in hospitals [30]. Another expert also adds that non-cytotoxicity and antibacterial properties are also highly important for medical applications [39].

4.4.5.3.5.2 Market analysis

European coated fabric expert says that for upholstery the most commonly used plasticizers are DOTP and DINP. DINCH is used to a small fraction in Europe but has some problems with the viscosity, which requires a good pumping and mixing system in the plant to be able to use it. So, it is not so common to use DINCH as primary plasticizer [30].

4.4.5.3.5.3 Discussion

Pevalen has shown good abrasion resistance, and if this can be confirmed, it is very good for upholstery. The soft-touch Pevalen brings to the fabric could be good for residential applications, but commercial is more concerned regarding abrasion and chemical resistance. Tests mentioned by CFFA should probably be done to make sure Pevalen is suitable. EFSA approval will also help here since a lot of these applications come in contact with human skin.

4.4.6 Common coated fabric testing parameters

This section contains a list of common properties to test for coated fabric and an evaluation of the relevance of these for each category to be able to see which properties are needed to prioritize to perform laboratory testing on and to know where there is missing data.

The following table (table 3) contains properties that are common to test on coated fabric with a short explanation. These were mainly obtained from CFFA “testing of coated fabric and films” but have also been complemented with testing the experts mentioned important.

Table 3 Properties to test for coated fabrics [6, 60, 68]

Property	Explanation
Abrasion	Abrasion tests are conducted on coated fabrics to test wear-resistance capabilities. Wear resistance is a material ability to withstand daily usage and essential attribute to test, especially for coated fabric used for upholstery, both in residential and commercial. Requirements for wear resistance depend on end-use application. Either Wyzenbeek method, Taber Abraser method or Martindale abrader can be used.
Heat ageing	Ageing tests are used to estimate how a material will change over longer periods of time. Changes to mechanical properties or visual appearance are observed after testing. Test parameters depend on geographic or topographic location. The test can be made for indoor and outdoor and in open or closed compartments.
Bursting Strength	Measure the force needed for the material to bursts.
Adhesion of coating to the fabric	The plastic coatings ability to stay coated to the fabric backing. This is done by measuring the force needed to separate the plastic coating from fabric backing.
Light ageing	Light ageing tests are done to simulate accelerated ageing of a material. Light ageing tests for indoor can be done with Xenon Arc Light Apparatus or a Carbon Arc Light Apparatus. Following properties may be examined after the test, stiffness, tackiness, crazing, color change, or any other deviation.
Weathering	For outdoor applications, light ageing is referred to as weathering. Both Xenon Arc Light Apparatus and a Carbon Arc Light Apparatus can be used, as well as a Fluorescent Ultraviolet (UV) Lamp Apparatus. Weathering can be done with a QUV test chamber.
Bacterial and Mildew Resistance	Measuring the growth of bacteria or mildew. It is up to the customer to decide whether the results are acceptable or not. Measuring bacterial growth on coated differ in relevance depending on en use application. Staining from bacteria or mildew can be an issue as well.
Chemical Resistance	The materials ability to resist absorption or extraction to a given chemical. E.g. oil, NaOH, water. This is a very important test. What chemicals to test depends on what the material might come in contact with. Limitations depend on the end use application. It is also important to do tests for different cleaning agents the material will come in contact with, for example, soapy water, alcohol and chlorine.
Cleanability	A material ability to be repeatably cleaned, without deteriorating performance. Materials used in close to human applications are often cleaned. Clean and care can be specified for the product, so the consumer treats it as intended.
Migration	Migration of plasticizer into nearby materials. For example, into food or plastics materials.

Extraction	Extraction of plasticizer out of PVC matrix. Affects the performance of the material given by the plasticizer.
Exposure to disinfectants	Applications that are exposed to excessive cleaning, such as hospital beds, need to withstand repeatable cleaning with disinfectants. Observe changes: color, gloss, surface deterioration, cracking, peeling, or hardening.
Cold Crack Resistance	Fabrics resistance to cracking when exposed to cold temperatures. The fabric is exposed to a specific temperature during a period of time and then folded or bent abruptly. The cold crack temperature is the temperature at which the coated fabric starts to show cracks. Roller or Mandrel method are examples of methods that can be used for testing.
Cold Flexibility	A materials ability to be flexible at a low temperature. Often determined by measuring glass transitioning temperature.
Flexibility	The flexibility of a material.
Dimension stability	A materials ability to maintain its original dimensions. Usually, by exposing the material to heat and then measuring dimensional changes.
Electrical and static resistance	Important for industrial applications such as conveyor belts. Avoid the risk of harming people or causing hazards. (expert)
Fire and Smoke	Testing a materials fire resistance and smoke release. Requirements differ depending on end-use application and customer-specific needs. In public spaces, flame retardancy and low emissions of toxic smoke increases the time to evacuate a building or vehicle and lowers the risk of inhaling toxic smoke. Flash and fire point: the flashpoint is the lowest temperature vapors are ignited by a flame. The fire point is the temperature where a flame is sustained for at least 5 seconds. The cone calorimeter test gives the ignition temperature and the density of the developed smoke.
Flex Resistance	Coated fabrics ability to resist repeated flexing. Visual determination of the fabric looking for cracking, whitening, crazing, or separation of coating from fabric backing.
Gloss	Measuring gloss of fabric. Maintaining gloss or gloss connected to tackiness.
Hydraulic stability	Hydrolytic stability is measured by exposing a specimen to wet environments and then determine resistance by measuring the degree of hydrolysis.
Lacquer or Varnish lifting	Coated fabrics capability to stay in connection with a lacquered or varnished surface without damaging either material.
Fogging	Volatile compound creating a surface on the windshield or window. Specifically for the automotive industry.

Odor Test	Smell test to examine if a material has an odor. Can be done right after processing or after a certain time period, as well as in connection with other tests such as hydrolysis or heat ageing.
Seamability	A materials ability to be sewn. Automotive companies normally have their own standards and tests of seamability. They also test appropriate sewing threads. In general, any fabric that will need a seam has to be able to be sewn in.
Seam Strength	Fabrics ability to withstand breaking in the seam or wire of the seam when subjected to force, e.g. pulling.
Shrinkage	Shrinkage is measured in percentage of decrease from original measurements. Testing shrinkage can be done by measuring a piece of coated fabric and immersing it in distilled water for a specific time than measuring the piece again.
Stretch and Set	Stretch and set of a coated fabric is tested by applying a weight to a strapping piece of fabric and then removing it. Stretch is measured in percentage of elongation in length right after the fabric has been exposed to the load and set is measured in the same way but a few minutes after.
Tackiness	Tackiness can be measured by performing a blocking test. This can be done by having two pieces of the same sample pressed against each other between glass plates and exposed to elevated temperatures. The pieces are then cooled in room temperature. When separated, does any adhesive appear on the surface or can the pieces even be peeled off each other intact.
Tearing Strength	Tearing strength is a way of determining a fabrics ability to withstands further tearing when a cut has been made in the fabric. After cut has been made, a force is applied to test the tear strength. This test can be performed by example the Elmendorf method, tongue method or trapezoidal method.
Tensile Strength, Elongation at break, Elongation	Tensile strength is measured by the force a coated fabric or other material can withstand before breaking. It can also be referred to as breaking strength. The elongation at breaking point is also important. Elongation at break is the difference between the length of the space between the claps holding on to the test piece at the beginning of the test and at the breaking point. Elongation refers to the stretch of the fabric. It is also important to know to what point the fabric can return to its original state when being stretched. Another way of describing this is at what point is the elongation not reversible.
Thermal Stability	A materials ability to withstand deformation or when exposed to high temperatures.
Touch and appearance	No official testing. The way the fabric feels and looks is quite important. Soft-touch or mimic leather, important in some applications. More important in residential furniture, automotive and not for public seating with heavy wear, e.g. subway seats etc.

VOC	Volatile organic compounds are emitting out of the material. Important to measure. Often limits to how much VOC or SVOC a product is allowed to emit.
Volatility	Loss of plasticizer due to its volatility.
Water Vapor Transmission	Measuring how much water vapor that can transmit through the fabric. Cover a container with water with a piece of material, then measure the weight loss of water after a specific time at a set temperature, to see permeability of the fabric.
Weight of Coating and Fabric	Measure the weight of coating and fabric separately only relevant if there is a need to know how much of the total weight that comes from the coating. In automotive applications, weight is quite an important aspect as the lighter the car, the more energy efficient it will be. A coating that is lighter might benefit from this.
Resilience Factor	For foamed fabric. When exposed to a force pressing down on the fabric, to what extend does it return to the original position.
Crocking	Crocking is a way of measuring color transferring from the surface of a coated fabric to another subject by rubbing. The test can be done using either a wet or dry cloth rubbing against the coated fabric. The cloth is then compared with a non-used exact sample of cloth and graded from excellent to poor depending on the visual appearance of staining.
Staining	A fabrics resistance to staining, often tested with common household product and chemicals. Stainability is measured by visual examination. After the product or chemical stain has been attempted to be cleaned off the fabric, examine stain in terms if no stain, slight stain, almost full stain, and no stain removed.
Denim staining	Denim staining is a test where a denim cloth is specifically used to rub against the coated fabric to measure staining. Specific standards are developed for this. Common tests within the automotive industry, especially fabrics for high-end cars need to withstand these tests to make sure the fabric they are suing is resilient. The stain is evaluated on how visible it is, usually compared to an untouched sample.

4.4.7 Gap analysis of important properties and lab data

Table 4 is an evaluation of the relevance of these properties in each coated fabric category that was analyzed in this thesis. Not all categories from table 3 are included, and some are combined with another due to similarity. The evaluation is subjective and based on opinions formed during the research through this thesis. The relevance of each property is graded from 1-5. With 1 being of low importance to 5 being of very high importance. 3 is the medium and cut of grade, meaning that the property is relevant but not most important to test right away. The property then gets a final score from combining all the individual scores which shows the overall importance of the property. At the end of the table there is a column called “Lab data”. This is colored green, yellow or red. Red being not data found and green being enough relevant data found. Yellow indicates that there exist some lab data in this field but there is need for improvement or that the data should be utilized different.

Table 4 Evaluation of property importance and gap analysis of internal lab data at Perstorp. Property importance being scored 1-5, with 1 being of low importance and 5 being of very high importance. Existing lab data is evaluated with colors, where green describe that relevant data exists, red describe that data is missing and yellow describe that some data exist but there is need for complementation.

Property	**Automotive**	**Clothing & Accessories**	**Upholstery**	**Marine**	**Outdoor**	**Indoor**		
	Importance						Total Score	Lab data
Abrasion	5	5	5	4	4	5	28	
Adhesion of coating to the fabric	4	4	4	4	4	4	24	
Bacterial and Mildew Resistance	2	2	3	5	5	2	19	
Bursting/ Tearing Strength	5	4	5	4	4	3	25	
Chemical Resistance	4	4	4	3	3	5 (medical)	23	
Cleanability	4	4	4	3	3	5	23	
Cold Crack Resistance/ Cold Flexibility	4	3	3	3	5	1	19	
Dimension stability	5	4	5	5	5	4	28	
Fire and Smoke	5	3	5	5	3	5	28	
Flex Resistance	5	4	5	4	4	4	26	
Heat ageing	5	3	4	4	5	4	25	
Hydrolytic stability	4	4	4	5	5	3	25	
Light ageing	4	4	4	5	5	3	25	
Migration	4	4	4	2	2	4	20	
Odor	5	5	5	3	3	5	26	
Seam Strength	3	4	5	3	3	4	22	
Stain resistance	5	4	5	4	3	4	25	
Stretch and Set	4	3	4	3	3	4	21	
Tensile Strength, Elongation at break, Elongation	4	4	4	4	4	4	24	

Touch and appearance	5	5	4	3	3	4	24	
Volatility/ VOC	5	5	4	3	4	5	26	
Weathering	1	2	1	5	5	1	15	

The properties scoring the highest grade of importance in table 4 were Abrasion, Dimensional stability and fire & smoke. This combined with that not sufficient data exist makes these properties considered highly prioritized in future laboratory work.

4.5 Laboratory suggestions

A lot of laboratory work has been performed at Perstorp, both for costumers, collaboration partners and for internal knowledge-building. After completing the market analysis, the coated fabric was considered to be the most prosperous close-to-human applications for Pevalen. Relevant properties to test for coated fabric has been researched and summarized in section 4.4.6. Out of the properties detected most important, suggestions for complementary laboratory work will be given.

This section includes an analysis of laboratory work done at Perstorp and suggestions for future work. Some include notions about testing done at Perstorp.

Abrasion resistance

A wear-resistant test has been done with Pevalen, DOTP, DINCH and Mesamoll, comparing abrasion between both equal hardness and equal phr of Pevalen. The test was made on films not coated fabrics. Pevalen showed better wear resistance, both with equal phr and hardness. This test was only with non-phthalates and did not include any ortho-phthalates, which are commonly used amongst coated fabrics. The test was made on film, not coated fabric. However, this test indicates that Pevalen has good potential in abrasion compared to the non-phthalates.

Suggestion: Perform new test including phthalates DPHP, DUP, DINP, DIDP. If performed on coated fabric, then the non-phthalate in the previous test should be included as well. Do tests on both film and coated fabric, as this is the most important aspects of coated fabric, especially for upholstery. Abrasion resistance is mentioned in other applications as well, so the results can be used for more than coated fabric.

Adhesion of Coating to Fabric

Peel testing with Pevalen vs DOTP was performed according to ISO 2411. The results indicated that there are no obvious differences between DOTP and Pevalen plastisol's.

Suggestion: This is not the most important aspect to test. Compare with other plasticizers that are common in coated fabric, such as DINP, DIDP, DPHP if the test is repeated.

Heat ageing

Thin PVC films with three different plasticizers (DOP, DPHP and Pevalen) were compared in terms of mechanical properties before and after ageing under humid and warm conditions. No significant differences were found, and the tensile strength and the elongation at break generally

stayed at the same level for all plasticizers during the time of the ageing (3 weeks).(70 degrees and 50% RH).

Suggestion: This test included DOP, often considered as a benchmark plasticizer, but should also include other general-purpose plasticizers, such as DINP, DOTP and DINCH, perhaps add a specialty such and linear phthalate to compare with as well.

When talking an expert, they stated that heat ageing is not an exact representation of how the material will behave in real life. Keep in mind what parameters that are used, they need to represent an environment that the material will be in. Make real-life test as well to compare with.

Dimensional stability

Suggestion: Very important, not only for coated fabric but also for flooring, wall covering and pool liners. Compare Pevalen, DOTP, DINP, DINCH and DPHP.

Light ageing

Fabrics are exposed to UV-light, both in indoor and outdoor applications. Climate conditions differ depending on what environment the fabric is used in. Arizona in North America has quite extreme heat during summers, and a material that works in Europe might not withstand the climate in Arizona. Humidity also plays a part in how the material reacts. [27]

UV-light stability testing with QUV chamber, measuring yellowness index, show good results for Pevalen, compared to DOP, DINP, DIDP, DPHP, DINCH and DOTP. This test covers all general-purpose plasticizers. QUV test is for outdoor but can give an indication to how the material will perform indoors.

Suggestion: Not considered very important but could compare with linear phthalates. Another one would be to make a realistic UV-test by placing material in a sunny window at Perstorp or at a location with a different climate.

Weathering

Weathering test is currently being done according to ASTM 4892-3 standard, comparing Pevalen in PVC film to DINCH, DOTP, DINP, DIDP and DPHP, as well as Pevalen with different stabilizers and additives. Color haze, tensile, weight, FTIR are measured. Test also includes outdoor test and UV exposed PVC put in darkness. Tests made on film not coated fabrics. There is also another study conducted at the moment, testing QUV and Outdoor exposure to Pevalen, DOP, DINP, DPHP, DIDP, 911P, 11P, DOTP and DINCH, covering all important general-purpose as well as two linear phthalates.

Weathering tests already made at Perstorp with QUV, comparing DOP, DPHP, DINP, DIDP, DINCH and DOTP, shows Pevalen having great stability.

Suggestion: As tests are being done at the moment, covering the most important plasticizers, no suggestion about this will be made.

Chemical resistance

Pevalen has been tested with distilled water, 1% soapy water, 1% n-Heptane and 1% NaOH in water, 10% ethanol, 50% ethanol, olive oil and engine oil.

Extraction test with water, soapy water, 1% n-Heptane and 1% NaOH in water has been performed with a comparison between Pevalen, DOTP, DINCH, DINP and Mesamoll. Pevalen showed lower extraction values to n-Heptane, which is an alkane solvent, compared to DOTP, DINCH and DINP. Low extraction to soapy water as well.

DINP, DOTP, DPHP and Pevalen was tested for extraction/absorption in oil for 7 days at 90 degrees. There were no large differences between the plasticizers. DOTP, DINP and Pevalen had a similar mass loss. Shows that Pevalen has similar oil resistance as DINP and DOTP. Pevalen has also shown good resistance to olive oil.

Suggestion: Perform more tests with common chemical cleaning solution and acidic solutions. Chlorine is also very important since it is used for cleaning of coated fabric and flooring as well as being added to water in pools. The chemical resistance standards from ISO or ASTM regarding chemicals should maybe be used to do a complete work trough of the suggested chemicals.

Cold Crack Resistance

This is important for coated fabric used were temperatures get low, such as automotive interior during wintertime.

Suggestion: Test with DOTP, DINP, DIDP, DPHP and DINCH.

Cold flexibility

Cold flex testing has been done on PVC films, comparing Pevalen to DOTP, DINP and DINCH. Testing had been done with a Mettler Toledo DMA1 with results given in glass transition temperature. Results are showing Pevalen having Tg -15˚Celsius, which was the worst out of the four. The test was made with equal phr.

Suggestion: Is the cold flex resistance dependent on the amount of plasticizer? Should equal hardness be tested instead of equal phr? Perform a new test with equal hardness and see if the results differ.

Stain Resistance

Stain resistance is very important for coated fabric, but also for flooring and wall covering. Products that are relevant to test depends on end-use application. The following products had been tested for staining: oil, baby oil, sunscreen, ketchup, mustard, bbq sauce, pen ink, lipstick and exhaust soot, in technical data sheet from XX (SUNDANCE) which can give an indication to what to test.

Suggestion: When it comes to staining, there are no tests made by Perstorp. Some common cleaning agents and stains would be positive to have data on for Pevalen, but this is not considered to absolute important to test.

Fire resistance and smoke generation

Very few tests have been made on fire resistance and smoke generation. These properties have been found to be extremely important and something that producers in many applications are willing to pay extra for. One test result showed that total smoke release was significantly lower for Pevalen than DINP, when compared with equal phr and shore hardness. Pevalen has shown the potential to be very fire-resistant and reduced smoke according to costumers to Perstorp.

Suggestion: Fire and smoke require complex testing that can probably not be done at Perstorp. Perstorp should prepare samples and send for testing. There are certain testing methods for upholstery, wall coverings and flooring that could all be interesting to have results from. It is important to thoroughly test Pevalen for smoke toxicity as well, since all positive fire properties are very cost reducing for a material producer.

Fogging

Fogging test between Pevalen, TOTM, DINP and DINCH, with both gravimetric and reflectometric, showed Pevalen having excellent properties in comparison with DINP and DINCH. TOTM performed the best, with Pevalen being only slightly worse.

Suggestion: General purpose plasticizers for automotive are DINP, DPHP, DIDP and DOTP, so the test should include all these. Automotive industry often uses TOTM and linear phthalates, but these are seen as more specialty. A new test should include DPHP, DIDP and DOTP.

Odor test

When Pevalen is hydrolyzed, valeric acid is created. Valeric acid has a very distinct smell with a very low detection level of 0.0026 mg/m3. This makes it important to use the right kinds of stabilizers when formulating with Pevalen. Many studies have been made from Perstorp showing good suggestions for stabilizers that work well with Pevalen and also which ones to avoid.

Several tests have been made on measuring the amount of valeric acid and odor of samples sent to Perstorp as well as samples made at Perstorp. The test has been made to determine what stabilizers are working with Pevalen or are not. As well as testing additives to reduce smell.

Suggestion: Make a summary of stabilizers, additives and process parameters that works with Pevalen as well as the different limitations surrounding processing and application.

Tearing Strength

DOTP and Pevalen were compared regarding tear resistance. DOTP had 30% higher tear resistance than Pevalen. Unknown composition of the films. Pevalen sample had 70 shore A hardness and DOTP had 82 shore hardness. Equal hardness might give better tear results for Pevalen.

Tear test with DOTP and Pevalen. They were made at two different temperatures, 118 and 120 degrees. Pevalen had higher tear strength at both temperatures (performed better). No further information about formulation was given in the report.

Suggestion: Redo tearing test with equal hardness and include DOTP, DINP, DIDP and DINCH.

Touch & appearance

One of Pevalen key attributes is the softness it brings to a coated fabric.

Suggestion: Not considered too important but making samples with other general-purpose plasticizers to showcase Pevalen advantage. Especially for producers of faux leather, since it mimics real leather and has soft touch.

VOC

VOC is an important aspect for all indoor applications. The VOC also needs to be consistent and not vary between batches or producers. Several tests have shown good results for Pevalen, both in PVC and on neat plasticizer. Neat plasticizers comparison with DINCH, DOTP, Mesamoll and Pevalen shows best results for Pevalen. In another test, VOC was measured on plasticizers in two different PVC formulations where Pevalen, DPHP, DIDP, DIUP and L911 was compared. Good results were obtained for Pevalen in both formulations. The other plasticizers results were almost double to Pevalen.

Suggestion: Create a summary of VOC comparison between Pevalen, DINP, DOTP, DINCH, Mesamoll, DPHP and other plasticizers where there are already results. Make additional tests on PVC with the general-purpose plasticizer DINP, DIDP, DPHP, DOTP and DINCH.

Volatility

Volatility has been tested of Pevalen, DINP, DOP, DOTP and DINCH on S-PVC. Pevalen performed best out of these. Tests on plastisol films between Pevalen, DOTP, DINCH, DINP and Mesamoll shows best results for Pevalen. Pevalen performed similarly to DINP. Both evaporation and active carbon were used as the test method.

Suggestion: Test was made at equal phr. Make a test at equal hardness instead, since less Pevalen is needed for the same hardness, to see if this could reduce volatility for Pevalen even more. Test has also been made with mixing Pevalen and TOTM at different concentrations. Volatility increased with the amount of Pevalen, and pure TOTM showed best results. Make similar test or calculations with DINP, DIDP, DINCH and DOTP together with TOTM. Reducing the amount of TOTM is cost-saving, so obtaining the same results with more Pevalen and less TOTM compared to the others could benefit Pevalen.

Extraction

Pevalen has shown low migration to PS in e. Since a lot of finished products contains PU, meaning that PVC would be in contact with PU, this would be relevant to test.

Suggestion: Make tests on the migration of Pevalen to PU.

4.5.1.1 Discussion

In general, it is good to always have a benchmark phthalate plasticizer such as DOP or DINP while performing a test. This because the phthalates are so extensively tested, and a lot of data exist regarding formulations with these. This makes it easier for the formulator to compare the results on Pevalen and evaluate it easier.

As Pevalen is aimed to be a general-purpose plasticizer, it is more relevant to test against these than with specialty plasticizers. Since a lot of the specialty has very high performing properties, and the question is if Pevalen has the possibility to compete with these properties at all. An example, Pevalen has great fogging resistance, but in comparison with linear or trimellitates, it cannot compete.

If a plasticizer is aimed to be a specialty, it has to have unique properties to compete. If Pevalen has some unique properties, such as fire retardancy and low smoke generation, then this could be more of a specialty aspect. Then again, it needs to compete with other specialty plasticizers in that field and tested. Not to forget is that there is usually a minimum requirement of each standard, and as soon as a plasticizer passes this, it is about the cost. Showing extremely good results does not matter if it is not asked for by the producer.

Since many of these tests does not only apply on coated fabrics but beneficial in other areas as well, these are the tests that are preferred to be prioritized. This includes abrasion and wear-resistance, fire properties, dimensional stability, cold crack resistance and chemical extraction to chlorine.

4.5.2 Design of experiments

A few of these laboratory suggestions should have been performed at Perstorp during this thesis work. Instead the design of the experiments will be described. The ones that would have been done are abrasion resistance, dimensional stability, and stain resistance.

These tests can be performed on either film or coated fabric. Film or coated fabric should be made from standard formulation, meaning no enhancing additives such as UV-stabilizers. Preferably make sample with Pevalen, DPHP, DINP and DOTP.

Abrasion resistance:

Taber Abraser is a machine that can be used to determine abrasion resistance. The test works by rotating a platform with the specimen on against two wheels made from rubber. Parameters of hardness, weight and test cycles depend on material and expected service performance [68].

Samples should be cut into a circle to fit the machine. The measurements according to CFFA is 4-1/8 inches. At least three samples of each plasticizer should be tested. Weight of specimen before and after test can be made to determine loss of material by abrasion. Otherwise visual examination can be used to determine how the material withstood the abrasion. Results can be expressed in weight loss of the mean of the three samples or by pictures showcasing the wear [68].

Dimensional stability:

Dimensional stability can be change in any dimension such as width or length. Shrinkage is one way of determining dimensional stability for coated fabric [48]. One test is preparing coated fabric, or coated paper backing if more suitable, with Pevalen, DOTP, DINCH and DPHP. Three samples of each should be cut out to the exact same measurements and carefully measured in each direction. ASTM D751-19 - Standard Test Methods for Coated Fabrics

includes this test [68]. CFFA gives the following test parameters that can be used: 250 x 250 mm pieces are immersed in distilled water for 30 minutes and then dried at around 200 Fahrenheit for additionally 30 minutes. Wait 8 hours, before measuring the specimen. The appropriate conditions are explained in the standard. Measure dimensions again. Shrinkage is defined as differences between before and after divided with the before measurement, usually expressed as percentage by multiplying with 100 [68].

Stain resistance:

Samples of coated fabric have appropriate chemicals applied for 2 and 24 hours, at atmospheric conditions. The stain should then be removed with for example a cotton swab, using a new one for each cleaning cycle of the stain. Clean with dry cotton swab or with cleaning agent, most important to be consistent with each sample and amount of cleaning cycles. For example, 10 cleaning cycles. Examine cleanability by how visual the stain is – no stain, slight station, stain almost intact and no stain removed [68].

5 Conclusion

The market analysis showed that plasticizer market is very price-driven due to the market being very mature. As long as the requirements are met, it is often a question about cost, when choosing a plasticizer.

The most common general-purpose plasticizers are still mainly the ortho-phthalates even though there is a movement away from using ortho-phthalates due to the health concerns that has been risen about phthalates. The movement is, however slow, and it is mainly regulation that drives change in this market. As the market is very price-sensitive, there is no economic drive to move away from the phthalates this has held back the switch from phthalates. Several experts have stated that it is unlikely for ortho-phthalates to stop being used without an official ban. DOTP and DINCH are the non-phthalates that can also be considered to be general-purpose plasticizer and are considered competitors to Pevalen among the non-phthalates.

Europe is at the forefront of moving away from phthalates and are increasingly interested in the environmental impact and the toxicity of plasticizers. Pevalen with a favorable toxicity profile and with the bio attributed Pevalen Pro could, therefore, be of high interest here. A suggestion is making an LCA to add and showcase, the life cycle of Pevalen being sustainable. Interest in environmentally friendly and sustainable choices are growing in Europe, and requirements are getting more stringent.

The USA focuses on non-phthalates, and therefore uses DOTP extensively, but are not are so much concerned about sustainable and environmentally friendly products. Positive aspects for Pevalen is being a non-phthalate and non-toxic, as well as DINCH not really existing on this market. A lot of older equipment exist here that are set for DOP, so Pevalen processing similarities could come in handy.

China is still behind on changing from phthalates with DOP still being the most used plasticizer, but production speed is one of the most important things here since the market is very competitive. Since Pevalen has shown fast processing properties and similar processing to DOP this could be beneficial here. China also relays on domestic production and are not looking for expensive import. So, therefore, a suggestion is to start production in China.

For a new plasticizer to compete on the market, it has been found crucial that either the product reduces cost by performing better which can speed up the process, or that the plasticizer is more efficient which leads to needing less product, or thirdly that the plasticizer has valuable properties that reduce the need for expensive additives or specialty plasticizers. Pevalen has the ability to increase processing speed, reduce the needed amount of plasticizer as well as to provide great UV-stability and low smoke properties which reduces the need for these additives. Many of the experts interviewed have stated that a plasticizer with good inherent fire properties is something that they are highly interested in and willing to pay extra for. The high softness of Pevalen also makes it possible for compounders to add fillers which are both decreasing cost

as well as reducing the carbon footprint and making the material more environmentally friendly. These are key points to focus on while presenting Pevalen to customers.

Although, speeding up the process is not always beneficial since a lot of equipment is set to a certain setting and cannot always be changed. As Pevalen has similar processing qualities to DOP, which a lot of equipment is built around, using it instead saves alterations and need for processing additives.

The analyze of the application segments showed that almost the same plasticizers seem to be used in each application that has been analyzed. Other plasticizers can be used but, in that case, due to specific performance requirements such as low migration or great fire properties.

Flooring and wall coverings are both indoor building products and have similar key requirements; low VOC, abrasion resistance, dimensional stability, chemical resistance, fire retardancy and low smoke generation. Their application market is hard to enter due to it being very price concerned as well as having high production rates. Pevalen benefits from having low VOC, good chemical resistance to oil and shown low smoke generation. To be successful in these fields, it is important to complement technical data on abrasion resistance as well as expanding the data on fire properties.

For food contact materials, the following key requirements have been found important: high flexibility, cleanability, abrasion resistance and chemical resistance. Since Pevalen has a good resistance to oil, it could be successful in targeting food industries that produce greasy products. Although, it is needed to consider possible issues with migration of Pevalen into the food as well.

Coated fabrics are considered a promising industry for Pevalen since it has low toxicity, gives a soft touch to the fabric, has low VOC, and good UV-stability which are all factors of high importance in this field. The most important properties to test on a coated fabric was shown to be abrasion resistance, dimensional stability and fire & smoke properties, so therefore, additional data on these properties are beneficial to increase Pevalen opportunities in this field. Another property that was shown important within many applications that Pevalen is aimed for was chemical resistance to chlorine and is therefore also of importance to test.

Although many compounders are willing to try a new plasticizer, all help with formulation processing parameters is appreciated since it reduces their time required testing. Therefore it is beneficial to be able to present guidelines regarding processing and additives more or less suited while working with Pevalen.

The thesis work has been quite extensive, and therefore, an even more in-depth analysis can be continued with regarding coated fabric with more experts interviewed in different fields for a continued examination of the aspects that are usually tested for coated fabrics. The different flexible PVC applications often have a lot of similarities when it comes to aspects to test. So, some results can be beneficial in more than just the coated fabric area. The next step would be

to perform suggested laboratory work and see if the results can provide extra beneficial sales points.

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