Year Out Industrial Placement Report
of
Vivek Bhurtun

Department of Chemical Engineering
University of Bath

With
DuPont Teijin Films U.K. Limited
The Wilton Centre
Redcar, TS10 4RF, UK

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Industrial Supervisor(s):
Dr Kieran Looney
Dupont Teijin Films U.K. Limited
G415, The Wilton Centre
Redcar
TS10 4RF
UK
Tel. no: 01642 572124

University Placement Visitor: Professor Barry D Crittenden
Placement Officer: H. Samuel

Summary:
Globally, polyester film has an abundance of applications including, but not limited to electronics, food and drink, packaging, advanced magnetic storage media, renewable energy and even medical applications. DuPont Teijin Films is the world’s premier producer of Polyethylene Terephthalate (PET) and Polyethylene Naphthalate (PEN) films specialising in a variety of the aforementioned end uses.
The analysis of all aspects of the finished film production process is of pivotal importance in delivering high quality end products to customer specifications. During the placement period (13 months), the Author has undertaken a variety of projects spanning an extensive range of applications as part of the Process Technology Department Team. Projects have included: Film Surface Temperature Model Development Using Convective Heat Transfer Analysis to Improve In Line Film Cooling, Experimental and Theoretical Mass Transfer Studies of Polymer Chip to Determine Diffusivity Calculation Limitations, Bench Top and Pilot Plant Scale Analysis of Purging Polymers for Plant Scale Purging Applications in Clean Film Production, Development of a Process Model for Moisture Ingress into Film Rolls Using Mass Transfer Analysis, and Analysis of Film Thickness Profile and Control Analysis to Optimise Die Shaping Performance on a Film Production Line.
In addition to the above, plant site visits, plant production trials, safety training, weekly group meetings, monthly company communication meetings, regular experimental and theoretical team work, report writing and communication skills development are just some of the proficiencies gained and responsibilities undertaken which the Author feels have made this industrial placement year an invaluable experience in becoming a highly motivated and professional Chemical Engineer.
List of Contents

List of Contents ............................................................................................................. ii
List of Figures .................................................................................................................. ii
1 Company Outline ........................................................................................................ 1
2 Work, Projects and Assignments ................................................................................ 1
  2.1 Polyethylene Terephthalate Polymer ..................................................................... 1
  2.2 Polymer Preparation and Handling ...................................................................... 3
    2.2.1 List of Projects .............................................................................................. 3
  2.3 Extrusion and Casting ........................................................................................... 4
    2.3.1 List of Projects ............................................................................................ 5
  2.4 Drawing and Heat Setting .................................................................................... 6
    2.4.1 List of Projects ........................................................................................... 7
  2.5 Slitting, Winding and Recovery .......................................................................... 7
    2.5.1 List of Projects ........................................................................................... 7
3 Additional Activities .................................................................................................... 7
  3.1 Site Visits .............................................................................................................. 7
  3.2 Suppliers and Customers ..................................................................................... 8
4 Training ....................................................................................................................... 8
  4.1 Safety ................................................................................................................... 8
  4.2 Mathematical Modelling ...................................................................................... 8
  4.3 Dramatrain ........................................................................................................... 8
5 Benefits ....................................................................................................................... 9
  5.1 Practical Work ..................................................................................................... 9
  5.2 Results ................................................................................................................ 9
  5.3 Meetings .............................................................................................................. 9
  5.4 Supervisor Comments ....................................................................................... 9
  5.5 Conclusion .......................................................................................................... 10
6 Acknowledgements ................................................................................................... 10
7 References ................................................................................................................ 11
8 Appendix A – Selection of Work Reports ................................................................. 12

List of Figures

Figure 1 - Structure of PET² ....................................................................................... 1
Figure 2 - A typical film production process from production of polymer, through filming to
  winding and recovery³ ............................................................................................... 2
Figure 3 - Single Screw Extruder³ ............................................................................. 3
Figure 4 - Twin Screw Extrusion³ ............................................................................. 3
Figure 5 - Simple diagram of end fed die³ ................................................................. 4
Figure 6 - Schematic of a Casting Unit, for thicker films, there would be a second drum to
  cool the film side exposed to the air³ ....................................................................... 5
Figure 7 - Typical layout for extracts and air handling units for modern thick film stenter³ .... 6
Final Placement Experience Report

One Year Industrial Placement with

Dupont Teijin Films U.K. Limited at

The Wilton Site, Redcar, TS10 4RF, UK
1 Company Outline

DuPont Teijin Films Limited (DTF) is the world’s leading differentiated producer of polyethylene terephthalate (PET) and Polyethylene naphthalate (PEN) polyester films and meets the global and regional needs of customers that value innovative and high quality films. Initiated in January 2000, DTF was established as a 50:50 joint venture between the two market leaders in polyester films at the time, E. I. du Pont de Nemours and Teijin Limited. Consequently DTF is the world’s leading supplier of polyester based films, specialising in film products, in-house expertise and related services for the construction, electronics, healthcare, identification and security, image printing and recording media, industrial, packaging and photovoltaics markets.

Applications are numerous including: traditional roofing and structural panels, solar control, steel protection, display, handleability or printability specifications, medical test strips (diagnostic devices), medical labelling, health cards, durable labels, flexographic printing plates, magnetic storage media, food packaging and photovoltaic backsheets. The nature of the rapidly expanding industry leads to the fast paced and highly innovative design of new services and applications to satisfy an ever increasing demand for economically viable products with novel end uses. Various brand names include Mylar®, Melinex®, and Teijin® Tetoron® PET polyester film, Teonex® PEN polyester film, and Cronar® polyester photographic base film.

DTF services Europe, the Middle East and Africa from its European Operating Headquarters in Luxembourg, operating plant in Dumfries (Scotland) and Global research and development centre in Wilton (UK), the United States of America from its production plant in Virginia, and Asia through the Asia Pacific Network in China, Indonesia, Taiwan, South Korea, Singapore, Australia and New Zealand. DTF services Japan from its Head offices in Tokyo and Osaka, production plants in Ibaraki and Utsunomiya and Development Centre and production plant in Gifu.

The global R&D Headquarters at the Wilton Centre, Redcar UK, provides technical and scientific support to DTF globally. The Wilton Centre R&D team comprises of Product, Process Technology, Intellectual Property, Information Systems, Finance and Commercial departments with a broad range of specialists providing dedicated support to DTF global operations. The Author’s placement comprised of 13 months spent in the Process Technology research and development group working on a variety of projects spanning a broad range of applications.

2 Work, Projects and Assignments

A basic overview of the process is explained in this section with a brief description of the projects the Author worked on in this specific area of the process, a selection of in-depth work reports on several projects can be viewed in the appendices.

2.1 Polyethylene Terephthalate Polymer

Polyethylene terephthalate (PET) is a semi crystalline polymer synthesized from a step-growth polycondensation reaction between Terephthalic acid (TPA) and Ethylene Glycol (EG)

\[ \text{O} \quad \text{C} \quad \text{O} \quad \text{C} \quad \text{CH}_2\text{CH}_2 \quad \text{O} \]

Figure 1 - Structure of PET

The conversion of polymer into biaxially oriented film can be described in 4 stages, which are summarised individually in the following sections.
Figure 2 - A typical film production process from production of polymer, through filming to winding and recovery.
2.2 Polymer Preparation and Handling

Polymer can be fed to the film manufacturing part of the process either directly from a continuous polymeriser or through a polymer melt system such as an extruder. With lines fed by extruder systems, there are often blending units and drying columns present, due to reduced process material efficiency (<100%)².

Recycled polymer (flake), is blended with virgin polymer to re-enter the process. In single screw extruder systems, drying is compulsory and usually takes place at 160°C -180°C to reduce the moisture levels to between 10 and 30 Parts Per Million (PPM). This is a requirement as the polyesters are susceptible to hydrolysis in the melt system (virgin chip is also crystallised prior to drying to prevent sintering) which results in a drop in Average Molecular Weight (AMW)².

![Figure 3 - Single Screw Extruder³](image3.png)

The diagram above shows a typical single screw extrusion melt system, these systems are susceptible to torque limits and can fail if polymer feed moisture content is high (wet). However this now presents less of a problem with the design of twin screw extrusion systems which use vacuum ports to draw off the moisture² simultaneously whilst melt processing.

![Figure 4 - Twin Screw Extrusion³](image4.png)

2.2.1 List of Projects

**Moisture Meter Analysis of E316A Breathable Polymer:** Aimed to compare the diffusivity of enhanced breathability PET Polymer and standard PET. Investigated the comparison between drying behaviour predicted by the in house model ‘POLYHAND’ and Karl-Fischer Titration analysis. This was based on two methods of estimating the polymer chip volume. The density method calculation and geometric method calculation resulted in diffusivities of the same order of magnitude (10⁻¹⁰ m² s⁻¹), but more importantly it was found that the increased breathability of the polymer arose from its higher equilibrium moisture content rather than its increased diffusivity (in comparison to standard PET of equivalent thickness and held at the same vapour pressure gradient across the film).
Suitability of IR Heater for Barium Polymer Metering - Dumfries D53 Line: Aimed to create a compact method of crystallising polymer for the addition of a second stream feeder. Investigated the suitability of a vibrating bed IR heater for metering and delivery of polymer chip to the Dumfries D53 production line. It was found that the heater suggested by the partner company did not meet the requirements to achieve the required Minimum Mean Film Temperature Rise (MFTR). Several other models were investigated and it was concluded that the MFTR (130˚C) could be achieved with heater width 1m and length < 10m.

Purging Polymers: Rapid grade changes are important for maintaining high process efficiencies. This project investigated the suitability of various polymers to purge lines of a polyethylene variant used in clean peelable film production. This involved carrying out bench top scale investigations with a vertical twin-screw extruder to determine how effective certain polymers were at purging the variant from the melt system.

2.3 Extrusion and Casting
After exiting the melt system the blended and dried polymer is extruded through a slot die, the aim being to produce a melt curtain of approximately uniform thickness. There is usually some sort of melt filtration unit present before the die to remove gels, catalyst residue and polymer degrade2,4.

The die can be either centre or end fed, and consists of a number of thermoviscous heaters positioned along its width heating the polymer as it forms the melt curtain. Gauge thickness measurements downstream monitor the thickness across the film width and adjust the heater set points via feedback control to correct thickness variations in the finished film. Increasing the heater set point increases the mass flow rate of the polymer at that point, hence thickening the finished film. The finished film profile can also modified by the actuation of mechanical bolts at the point that the polymer exits the die. Usually, very fine profile adjustment can be achieved using a combination of thermoviscous heater set point modification and mechanical bolt modulation2,4.

The casting unit is used to crash cool the melt curtain (which is typically between 280˚C-300˚C) through the crystallisation temperature band and produce a film of approximately uniform thickness with no surface defects ready for drawing in the machine and transverse directions (increased crystallisation in the film at this point can cause haze, brittleness and line splits downstream). Thus, most casting drums are comprised of copper (high coefficient of heat transfer) coated in a highly polished hard chromium finish and are cooled using water (typically between 10˚C-15˚C) which is re-circulated through a heat exchanger2,4.

![Figure 5 - Simple diagram of end fed die](image)

For a thin film (30um finished film thickness), a single casting drum would suffice, however for thicker films (125um finished film thickness) where the thickness of the film becomes a
limiting factor to the heat transfer from the drum to the film side exposed to the air, a second drum is used in series. This is often called a take off roll (TOR).

![Diagram of a Casting Unit](image)

Figure 6 - Schematic of a Casting Unit, for thicker films, there would be a second drum to cool the film side exposed to the air\(^2\).

The rotation of the drum causes the entrainment of air forming an air layer between the film and drum surface. This causes a decrease in the heat transfer from drum to film thus impacting the cooling. To prevent this, a pinning wire or blade electrode is stretched across the width of the drum just below the die. The corona discharge from the electrode pins the melt onto the drum surface, which is earthed. The entire drum must also rotate smoothly, as vibration disturbances effect finished film surface quality\(^2,4\).

The majority of the work completed has been mathematical modelling of film properties (Surface and through film temperature profiles and crystallinity profiles) on the casting unit. This area of the process is pivotal, as the properties of the film have to be robust enough to survive two directional drawing without splitting.

### 2.3.1 List of Projects

**Thickness Capability of Semi-Plant Facilities:** Process modelling using DTF in-house models to confirm the upper operating limit and thickness capability of the semi-plant facilities and changes required to extend the current window of operation.

**D52 Cast Edge Cooling Model:** This project involved investigating ways to improve (film edge) robustness for stenter feeding on the Dumfries D52 operating. Film temperature and crystallinity profiles were generated and heat transfer calculations to model in line air coolers were carried out using DTF in-house models, to improve process variables in the cast and forward drawn film. From the modelling results it was found that widening the main air horn nozzle by a factor of 2 would impact the process favourably. This was implemented on the line and several successful process trials followed.

**D53 Die Optimisation:** The aim of this project was to correct a low spot in the thickness profile on a die used on the Dumfries D53 operating line and is routine maintenance carried out to prolong the life of existing hardware. This involved manually modifying the die gap and checking to see the effect this had on the thermoviscous heater temperature profile. It was found that in the case where there is a low spot adjacent to a high spot in the thickness profile, it is impossible to correct the heater profile. However it was considered that since the edges of the film are trimmed from the main body, the thick spot could be shifted into the edges.

**Low Spot Correction of D53 Body 2 Lipset 3 Die:** Made minor corrections to the die gap and heater profile for a die used on the Dumfries D53 operating line which was to be reinstated shortly.
D51 Thick Film Analysis: Heat transfer analysis of the Dumfries D51 casting process was carried out to determine a casting film path which would further increase the robustness of the already existing thick film process (125um). During this project a casting path for thicknesses from 30um up to 125um was investigated and tested during trials. This project was carried out to investigate thickness capability to cope with on going product differentiation.

2.4 Drawing and Heat Setting

After the film has exited the casting process, it usually enters a zone of pre-heating where opposing sides of the film are heated incrementally over a series of heated rolls, until the temperature of the film is approximately 15˚C above the T_g. The forward draw physically stretches the film and strengthens its mechanical properties in the machine direction. This is usually achieved using two rolls, the second of which is run a certain fraction faster than the first. Stretch ratios of typically 3.5:1 are utilised, this additional stress in the material cause the molecular chain segments to align in the direction of stress and raise the general strength and tensile modulus of the film by a factor of approximately 3^{2,4}.

The second part of the drawing process occurs in what is known in the industry as a ‘Stenter’ oven. This piece of instrumentation consists of several zones, which play a different part in the film production process. At the entrance to the Stenter, the edges are gripped in clip grippers, which run on mechanically driven rails, in this way, the film is stretched as the rails widen. This occurs at temperatures > 100˚C and at stretch ratios typically between 3 and 4. Similarly to the forward draw, the sideways draw, or stretching in the transverse direction (TD) orients the molecules in this direction and strengthens the transverse film properties. The level of orientation is usually equal to that encountered in the machine direction, at this point, any molecules not already aligned become aligned in the TD, but also some MD aligned molecules realign in the TD. At this point in the process, the film is said to be anisotropic^{2,4}.

The final stage of the stenter is often called the ‘crystalliser’ and consists of 2 or 3 zones each of which have separate temperature controls and mechanical adjustment to modify the lateral dimension of the web. In this way a range of thermal and mechanical finished film properties can be engineered. The crystallisers are specifically designed to give the film crystalline morphology to lock in the properties acquired in the forward and sideways draw. The temperatures at this point in the process can be as high as 230˚C^{2,4}.

Figure 7 - Typical layout for extracts and air handling units for modern thick film stenter^{3}
2.4.1 List of Projects

**D51 Thick Film Production:** Investigated cast film and forward drawn film thickness gauge profiles at several product trials from trial samples at a number of film thicknesses to check film edge thickness variations for several film grades.

**Cook Shrinkable Film:** It is often a requirement for film to have low shrinkage, the opposite is wanted for this film, which is used as shrink wrap for food and other goods. Attended several trials on the Semi-Tech site and the Dumfries D51 operating line monitoring conditions to increase process robustness. Carried out Shrinkage tests at the D51 operating line to determine the machine direction and transverse direction percentage shrinkage was to customer specification.

2.5 Slitting, Winding and Recovery
The edges clamped in the clip grippers are often a lot thicker than the centre of the film. Edge cutters are used to separate the edges from the bulk film and these are either re-extruded into pellets or flaked and recycled back into the process with virgin polymer. The edge trimmed film is then wound onto mill rolls for storage, and can either be cut into slit rolls at the end of the stenter, or taken and cut on a specially adapted piece of instrumentation specifically designed to create slit rolls of film to customer specification²,⁴.

2.5.1 List of Projects

**Moisture Ingress Model:** The aim of this project was to create a working model to predict the moisture uptake by slit rolls, mill rolls and film cartridges over certain time periods and in various environmental conditions. Utilising Visual basic for applications (VBA), the Author constructed an interface for the pre-existing form of the moisture model. This model was adapted from a previous model for calculating the permeation of moisture through multi layer films. The model now has a new interface, has been tested to destruction for numerical stability and all the post processing calculations checked and errors corrected.

**Preliminary Design of Heated Air Delivery System for Continuous or Pulsatile Flow in a Thermo Forming Process for Food Packaging:** This project involved improving an existing thermoforming process to increase the adhesion characteristics between film and cardboard trays, for potential use in the food packaging industry. The project involved the preliminary design of a pressure vessel air heating system to ensure film temperatures were sufficiently high enough for good adhesion with the cardboard packaging.

3 Additional Activities

3.1 Site Visits
The Wilton site is located on the North East coast England in an Industrial district. Hence the Mini (finished film width ≈ 0.3m) and Semi-Plant (finished film width ≈ 1.5m) scale facilities are both located within the Wilton Site itself. All trials of novel products take place on these lines, before the process conditions are replicated onto larger lines at the Dumfries production plant (finished film width up to ≈ 9m). The Author has taken part regularly in investigative trials on the Semi and Mini scale plants, logging process conditions and taking polymer and film samples for post trial analysis. The Author was also shown the polymer production plant and took part in several process communication meetings while attending trials at the Dumfries production plant.
3.2 Suppliers and Customers
Since DTF operates globally, suppliers and customers are typically brought to the R&D site to observe the facilities for themselves. Recently the Author took part in a supplier communications meeting with the Pall Company, discussing the possibility of using Pall melt filters in the Dumfries site extrusion melt systems; this was both interesting and engaging and once again highlighted the importance of networking and ensuring good relationships and continual respect and cooperation with industrial partners, to ensure line robustness and ongoing mutually beneficial connections.

4 Training

4.1 Safety
As part of the safety culture at DTF, all employees are required to undertake basic competency and safety training in all the laboratories involved in their work and all pieces of equipment used. Consequently the Author has been trained in both the wet and dry laboratories to cut film, measure film thickness in the machine and transverse directions using a mercer gauge, determine moisture content of polymers using Karl-Fischer Titration, determine the intrinsic viscosity of semi plant scale samples using a Davenport Viscometer and operating a mini twin screw extruder to determine the suitability of various purging polymers. Basic Safety around the work place is encouraged consistently; monthly communication meetings review incidents and prescribe ways to avoid future occurrences.

4.2 Mathematical Modelling
For several projects it has been necessary to use many of DTF’s in-house models. Training courses for each of these models were undertaken to understand the theory involved and also how to utilise each model efficiently. A brief summary of each model follows:

THOR: Transfer of Heat on Rolls, models film properties (temperature, crystallinity) through Casting and Forward Draw.

Storm 2003: Pre cursor model to THOR, models film properties (temperature, crystallinity) through the Stenter oven. This model can also be used for Stenter oven design.

IR Heater Model: Allows calculation of the Mean Film Temperature rise from specific user inputs such as heater length, width, web velocity, heater power density etc.

Die Gap: Polymeric flow modelling of melt flow through the die.

Polyhand: Models polymer handling and drying behaviour and can generate dynamic moisture curves which can be compared with Karl-Fischer titration results.

Moisture Ingress Model: The Author developed programming skills in Visual Basic for Applications (VBA) by helping to rewrite and refine this model, building it an interface and reworking post processing calculations. The model predicts the moisture uptake into film cartridges, slit rolls and mill rolls.

4.3 Dramatrain
As part of a new initiative to promote team work and communication, an interactive drama based training workshop was trialled by DTF entitled ‘Dramatrain’. This involved the workforce being split up into teams of equal number and participating in several workshops to highlight situations that could be encountered in the workplace at all levels of employment. Workshops involving observing situations unfold in real time presented by actors, to acting the situation out yourself
were all part of the workshop which took place over a full working day. Over the course of the day, participants learnt interaction techniques to prevent negative confrontations and ways to communicate effectively to ensure maximum efficiency. The ethos of a company operating safely and addressing the needs of its employees was also addressed. Not only did the workshop provide a good opportunity to get to know employees from other departments and teams, but also gave an opportunity to witness situations as an observer, allowing a new perspective on working relationships at all levels.

5 Benefits
The 13 months spent with DTF have been both rewarding and challenging in all respects. The Author feels that the experience has provided a large insight into how an industrial engineering company operates.

5.1 Practical Work
The trials have provided an opportunity to learn about process instrumentation and control, and experience it first hand, but also provided a link between design and mathematical modelling of processes, and how this translates in line. The trials have provided a valuable opportunity to observe the full life cycle of the industry, from design of processes and instrumentation in order to achieve certain film specifications, to installation/modification and operation of processes/equipment.

5.2 Results
The result of much of the mathematical modelling to solve process issues at the Dumfries operating plant has resulted in the Author attending several trials on the main lines to observe the results of modelling simulations being put into operation to solve certain process issues. This has been particularly valuable in understanding many of the process issues that surround scale-up in industry, but also refreshing to see the work undertaken implemented directly. The Author was also shown the polymer production plant and took part in several process communication meetings while attending trials on site.

5.3 Meetings
Attending the weekly process team meetings has improved the Author’s communication skills, learning to present/communicate the essential points of work across to the team while keeping the content sufficiently technical. The monthly communication meetings have given an insight into DTF global functions while providing at the same time an introduction to business operations at an industrial scale.

5.4 Supervisor Comments
Vivek has performed at an exceptionally high level in an R&D environment and made a valuable contribution to the sections work in all the areas he has participated in, which have been many given his enquiring mind, enthusiasm, initiative and hard work he has demonstrated.

Vivek has contributed to three production plant investigations, two involving heat transfer studies in cast film cooling and subsequent heating for stretching, taking plant data and building reliable models of both processes and the third involving deep data mining and analysis of film thickness profile and control analysis to optimise die shaping performance on a film production line. In the laboratory Vivek has supported a number of projects: using Karl-Fischer titration analysis to determine moisture contents of polymers used in the production of novel films and performing a twin-screw extrusion study to select appropriate purging polymers for a novel polymer on our pilot scale facilities.

On the pilot plant, Vivek has assisted in the development of a number of novel products on both our mini and semi-plant scale facilities, recording and analysing process data to predict product
processing history for subsequent developments and scale-up. Vivek has evaluated a novel polymer heating and drying process for potential retrofitting to the plant and a customer’s tray thermoforming process, developing a number of novel design options for them. More recently Vivek has developed his programming skills which have allowed him to extend our moisture ingress model for rolls and cartridges of wound films, demonstrating a sound grasp of transport phenomena and numerical analysis first principles. Vivek has proven to be punctual, hard working and reliable in all that he has undertaken. He has written an excellent set of reports and presentations which he has delivered to his internal customers. He has worked extremely well with everyone in the group, and interacted well with the wider R&D community in DTF and has always shown a willingness to tackle new topics and challenges, a sure sign that he can have a successful technical career if he so chooses in the future. An outstanding year’s work.

5.5 Conclusion
The Author feels that the biggest benefit from this placement year has been the learning and refinement of essential technical chemical engineering skills, such as problem solving, data analysis, process modelling, design and engineering report writing, whilst simultaneously refining key skills such as effective communication, team work and time management.

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Dr Kieran Looney – Kieran has been a great help this year both in and out of the workplace. A critical factor in the overall placement experience is the supervisor, and Kieran has listened, guided, and challenged the Author, providing just the right balance of assistance and independence to ensure that the most has been made out of every new situation.

Pierre Moussalli – Pierre who the Author has worked with on a number of projects has been of great help especially with the physics aspects. He has always had the time to answer questions work or otherwise related and has consistently challenged the Author to methodically and logically find answers to questions independently. The Author feels that his problem solving skills have been put through their paces and significantly improved due to the work undertaken with Pierre’s assistance and supervision.

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7 References

3. Courtesy of DuPont Teijin Film UK Ltd, This image may not be reproduced without permission.