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RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

Solution Proposals for Fires Occuring in the Laminatoin Units of Inline Lamination Machines

İnline Laminasyon Makinalarının Laminasyon Ünitelerinde Meydana Gelen Yangınlar İçin Çözüm Önerileri

Hasan Uğur ÖNCEL [1], Emre RESULOĞLU [2]

[1]*TC İstanbul Gedik Üniversitesi, Sağlık Bilimleri Fakültesi, 34906, İstanbul, Türkiye*
[2] *TC İstanbul Gedik Üniversitesi, Lisanüstü Eğitim Enstitüsü, 34906, İstanbul, Türkiye*

Abstract
In general, a flexible packaging factory consists of extrusion machines for film production, printing machines for printing on packaging (using inks), lamination machines for making multilayer structures with various substrates (using adhesives) and slitting machines to bring the produced packaging to the final dimensions for use in the food product packing process.

The inks and adhesives used in printing and laminating machines must be dissolved and diluted in order to be applied and ethyl acetate is commonly used as a solvent. The mixture ratio of solvent in the total solution can reach up to 80%. Ethyl acetate, a highly flammable substance, is the cause of many fires in the printing industry. Although printing and lamination are traditionally two separate processes done independently of each other, increasing competition and productivity requirements have guided machine manufacturers to make these two processes on a single machine and eventually led to the realization of inline printing-laminating machines. Such machines operate continuously, using automatic splicing of reels of base material to keep running without stopping or even slowing down.

In the flexible packaging sector, ethyl acetate fires generally occur in the enterprises' printing and lamination machines, along with ink and adhesive preparation areas. In this study, the causes of fires occurring in an inline rotogravure printing machine's lamination units after the automatic splice during lamination of printed polypropylene with metallized polypropylene are examined and the precautions to be taken to prevent these fires are discussed.
Keywords : Inline printing-lamination machines, fire, ethyl acetate, adhesives, packaging factory, safety

Öz
Genel olarak bir esnek ambalaj fabrikası, film üretimi için ekstrüzyon makinalarından, mürekkep kullanarak ambalaj üzerine baskı yapan baskı makinalarından, çeşitli yapıştırıcılar vasıtasıyla çok katmanlı yapılar elde edilmesini sağlayan laminasyon makinalarından ve üretilen ambalajları ürünlerin paketlenmesine el verecek şekilde nihai boyutlara getiren kesme makinalarından oluşur.

Baskı ve Laminasyon makinalarında kullanılan mürekkeplerin ve yapıştırıcıların uygulanabilmesi için çözülmesi ve seyreltilmesi gerekir ki etil asetat bu işlem için kullanılan solventler arasında en yaygın olanıdır. Çözücünün toplam çözücü içerisindeki karışım oranı %80'e kadar ulaşabilir. Son derece yanıcı bir madde olan etil asetat, baskı endüstrisindeki birçok yangının nedenidir. Baskı ve laminasyon geleneksel olarak birbirinden bağımsız olarak yapılan iki ayrı işlem olmasına rağmen, artan rekabet ve verimlilik gereksinimleri makina üreticilerini bu iki işlemi tek bir makinada yapmaya yönlendirmiş ve nihayetinde inline baskı-laminasyon makinalarının hayata geçmesine yol açmıştır. Bu tür makinalar durmadan hatta yavaşlamadan, birbiri ardına gelen hammadde bobinlerini otomatik olarak birbirine eklemleyerek sürekli olarak çalışırlar.

Esnek ambalaj sektöründe etil asetat yangınları genellikle işletmelerin baskı ve laminasyon makinalarında, mürekkep ve tutkal hazırlama alanlarında meydana gelmektedir. Bu çalışmada, bir inline rotogravür baskı-laminasyon makinasının laminasyon ünitesinde, baskılı polipropilen filmin metalize polipropilen film ile laminasyonu sırasında otomatik ekleme sonrası oluşan yangınların nedenleri incelenmiş ve bu yangınları önlemek için alınması gereken tedbirler tartışılmıştır.
Anahtar Kelimeler : Inline baskı-laminasyon makinaları, yangın, etil asetat, yapıştırıcı, ambalaj fabrikası, iş güvenliği

I. INTRODUCTION

The main inputs for the printing and lamination operations used to make packaging films are film, ink and adhesive. Inks and adhesives used in the printing industry can be water or solvent-based, meaning that either water or organic solvent is the type of solvent used for a given ink or adhesive. Solvent-based inks and adhesives are widely used in rotogravure printing and lamination machines due to their ability to evaporate and dry quickly with less energy than needed for water.

Corresponding Author: Hasan Uğur ÖNCEL, Tel: 0 532 2711347, e-posta: ugur.oncel@gedik.edu.tr
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Chemicals such as acetone, ethanol, ethyl acetate, propanol, propyl acetate, methyl ethyl ketone and toluene are included in the group of solvents.

Ethyl acetate is the preferred type of solvent used in rotogravure printing machines due to ease of use with many ink and adhesive systems, availability of recovery systems, cost advantages, and relatively minor impact on employee health compared to other organic solvents. The use of this highly flammable and combustible solvent brings with it many safety risks, especially the risk of fire. Therefore, the prevention of fires involving ethyl acetate is of vital importance in the printing industry [1].

The three essential elements for a fire to occur are combustible material, oxygen, and heat.

In this study, the combustible material is ethyl acetate, which is used extensively in printing and lamination machines.

Another of the three main components required for a fire to occur is oxygen. Analysis reveals that the probability of ignition of ethyl acetate at a concentration of 2.5% at 1 bar and 100°C is 10% when the oxygen concentration is 9.40%, and 50% when the oxygen concentration is 9.46%.

Considering that the production in the printing sector takes place under normal atmospheric conditions and the oxygen content in the air under these conditions is considered to be 21%, it can be clearly seen that ethyl acetate vapor with a concentration between LEL-UEL can easily be ignited if it encounters a sufficient heat source [2].

The last of the conditions for the fire to occur is the heat source. The energy sources that cause ethyl acetate to ignite in printing and lamination machines can be listed as static electricity, the heat generated by friction and flame sources.

Fires caused by ethyl acetate are frequently reported in factories operating in the flexible packaging industry [3].

These frequent fires give rise to significant costs, serious productivity loss and sometimes loss of life and property.

In this study, fires occurring at the entrance to the drying tunnel of an inline rotogravure printing machine's lamination unit, following the automatic splice during lamination of printed oriented polypropylene ("printed OPP") with metallized oriented polypropylene ("metallized OPP"), are examined to determine causes and to discuss potential solutions. Such fires were reported in several factories of a global packaging company and became a chronic problem in the Turkey factory.

II. MATERIALS AND METHODS

In this study, reports for fires occurring at the entrance to the drying tunnel in several factories were examined, along with fire reports and in-situ evaluation of fires with printed OPP/metallized OPP that occurred in the Turkey factory. Other film types subject to the same process were also evaluated. Repetitive fire incidents were observed to occur during the passage of the splice between the finished and the new reel of metallized OPP through the drying tunnel. The "tail" of the new reel from the unwinder unit is attached to the film unwinding from the finished reel with double-sided tape. This combined "splice tail" then passes through the first drying tunnel of the 11th unit.

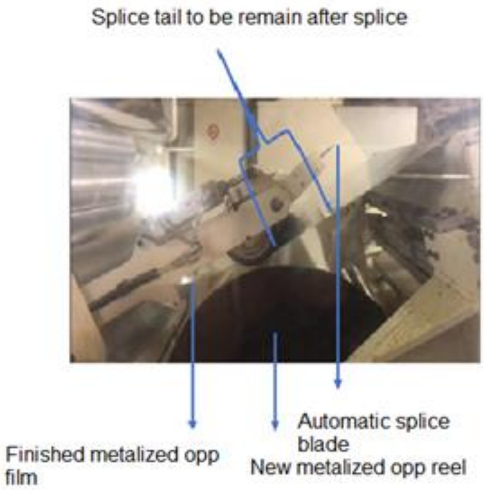


Figure 1. Automatic splicing unit

At a machine speed of 250 metres/minute, the splice tail reaches the lamination unit approximately 5 seconds after the automatic splice takes place. For reasons of food safety, the metallized surface of the metallized OPP should not come into contact with the food product, therefore the metallized surface is the one making with contact the adhesive cylinder to be coated with solvent-based adhesive before entering the drying tunnel. Fires were observed to occur synchronously with the entrance of the splice tail into the tunnel.

After drying, the metallized OPP film (with dried but still tacky adhesive) and the printed OPP film are brought into contact in the lamination roller group located in the second drying tunnel of the 11th unit. No flames were observed at any time in the second drying tunnel.

Following the fire, the film breaks; the machine then detects the loss of tension in the film via a load cell and automatically stops. With the machine stopped, the fire in the tunnel itself ends but continues to propagate onto the adhesive trolley.

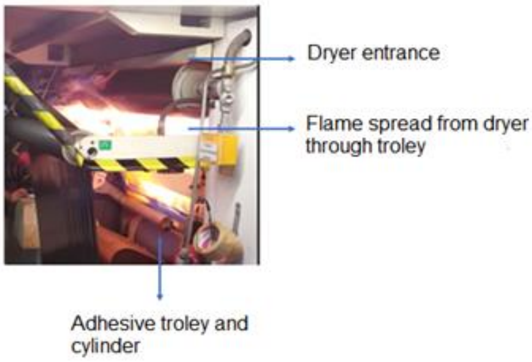


Figure 2. Fire incident experienced

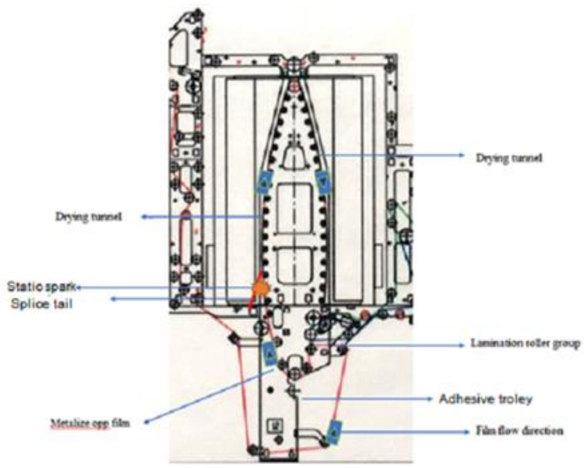


Figure 3. Lamination unit with fire

In light of the data obtained from the observations, the root cause analysis of the recurrent fires was made, and the result was reached by applying the Ishikawa method.

2.1. Measurement

Indications of friction (scratches, lines, discolouration etc) were searched for in the dryer tunnel and adhesive trolley and no evidence was found. Temperature measurements of the roller bearings in the unit were made, and the values were found below 36 ^{o} C which is accepted normal in printing industry considering the boiling temperature is 77 ^{o} C for ethyl acetate. Before the dryer enters the tunnel, a device (Fraser 710 static meter) was used to measures the level of static electricity on the metallized OPP film in units of kV from a distance of 100mm. The static electric charge on the film was measured as 0 kV. The average ethyl acetate LEL values in the dryer tunnel were determined to be between 22-27% by utilizing the Honeywell catalytic LEL sensors in the dryer tunnel. These values were recorded for each ignition experienced at different times.

The surface and insulation resistance of the printing impression rollers used during the fires that occurred in the unit were measured using a Megger MIT 420 resistance measurement device. It was seen that a refurbished ("covered") sleeve was used in all but one of the flashes, but one fire also occurred when a new ("original") sleeve was used.

Table 1. Resistance values of the printing impression rollers used in the lamination unit at times of fire accidents.

Sleeve Type	Surface resistance 1	Surface resistance 2	Surface resistance 3	Insulation resistance
Covered	39,6 (MΩ)	41,6 (MΩ)	63,6 (MΩ)	8,2 (MΩ)
Original	20 (kΩ)	20 (kΩ)	20 (kΩ)	< 1(MΩ)

The humidity level of the working environment was measured by two digital moisture measuring devices in order to verify against each other. The relative humidity of the production environment varied between 17-39% during the periods when fires occurred. The electrostatic printing assist system's voltage value were obtained from the machine control panel and was determined as 27 kV. It was observed that the system was switched off (no voltage applied) in the unit where the fire occurred.

2.2. Material

Flames occur only when the splice tail passes through the first tunnel shortly after the metallized OPP film and the new film are spliced, from which point the splice goes to the lamination unit to bring together the printed OPP and metallized OPP film. The surface of the laminated metallized OPP film is covered with aluminum. After the splice, the OPP surface of the tail part remaining behind the joint is in contact with the metallized surface of the film to which it is connected by double-sided tape. Although printing and lamination of materials such as OPP-opaque OPP, polyester-opaque OPP, OPP-OPP, co-extruded polypropylene-metallized polyester were performed on the same machine and with the same production method, no ignitions were observed with any film type other than metallized OPP film.

It is known that the impression roller, which ensures the film makes contact with the steel cylinder providing the adhesive transfer, was refurbished as a result of wear. This roller was linked with one sequence of repeated fires. However, in one of the ignition cases it was determined that a non-refurbished roller with surface and insulation resistance values below the 1 MΩ value recommended by the sleeve manufacturer was used.

The grounding condition of the adhesive unit and the equipment in the chamber was checked and resistance was not detected, indicating that grounding condition was good which is below 1 ohm.

The lamination adhesive consists of 30% solid substances mixed with 70% ethyl acetate solvent.

2.3. Machine

The machine consists of 12 units in total, with the first 10 units for printing, the 11th unit for lamination, and the 12th unit for application of cold seal (a kind of water-based coating). The 11th and 12th units each have two drying tunnels. Ignitions were experienced in the first drying tunnel of the 11th unit of the machine.

The machine was manufactured in 2006 under the relevant European standards and was installed in a factory of the enterprise in Belgium. No fire had been reported for the 11th or 12th units of the machine by the factory in Belgium, which did not produce a product that requires cold seal application after lamination and used the 12th unit as a lamination unit.

In 2017, the machine manufacturer revised the 12th unit to apply cold seal and the 11th unit was modified to also complete the lamination process. However, all units' parameters are the same, and both units are connected to the same exhaust line on which the same ventilation fan works. Other factories throughout the enterprise used machines without revisions, i.e. no modifications to do lamination in the 11th unit, yet several fires were reported during the lamination of OPP-metallized OPP films on both these same-brand unmodified machines and also on other brands of machine. Therefore, it is believed that the modification of the units in the Istanbul machine did not exacerbate the problem with fires.

All units are connected to the suction line of the recovery facility to send their exhaust gases to the solvent recovery system.

Inside the drying tunnel of the 11th unit, there are teflon coated aluminum rollers with a distance of 20 cm between them. The machine can automatically combine the reels to make 40-50 cm additional tail. There are static neutralization bars at the entrance and exit of the machine's 11th unit, and the electrostatic printing assistant (which applies controlled levels of static electricity to aid ink pick-up by the film) was not active in this unit.

In the first period where fires were often occurring in the dryers, positive pressure was being applied, meaning that the amount of hot drying air blown into the tunnel was greater than the air removed by the exhaust.

When negative pressure was applied in the tunnel fires also occurred, but the duration of observation of flames from the outside of the tunnel was prolonged and the severity of the fires decreased dramatically. As evaporated ethyl acetate suction is limited in dryer under positive pressure condition, combustible metarial accumulation causes both to be LEL level exceeded and fire to be large and severe. Conversely as negative presure means sucked air is more than blown air, in the dryer under negative pressure condition, evaporated ethyl ecetate accumulation would be less, as a result, possibility to be reached LEL level unlikely or possible fire intesity would be lower.

2.4. Method

In the production process where fires occurred, printed OPP film and metallized-OPP film were laminated in the 11th unit with the metallized surface “sandwiched” in the middle.

The finished laminated film and the new reel are automatically spliced to each other, and a 40-50 cm long tail is formed during the splicing. The OPP surface of the bottom makes contact with the metallized surface of the film to which it is attached.

The width of the lamination film is 1 m.

Machine speed is 250 m / min.

In the lamination unit, the adhesive is applied so as to leave 2.5 g / m² of solid material on the film after the drying process. Therefore, before entering the drying tunnel, there is liquid adhesive on the film at 8.33 g / m² per square meter.

The 11th unit dries the applied adhesive layer by evaporating ethyl acetate at 110^{o} C in the first drying tunnel and 80^{o} C in the second tunnel.

In the second drying tunnel, the average LEL value decreases to 12%. Therefore, it is understood that the largest part of ethyl acetate evaporates in the 1st drying tunnel.

2.5. Human factors

The machine senses that the tension on the ruptured film has reduced to zero after the fire, and automatically stops. Starved of fuel (no further liquid adhesive entering), the fire in the tunnel ends.

The ongoing fire in the unit trolley caused by propagation of flames out of the bottom of the dryer tunnel was extinguished manually by operators using CO2 extinguishers. The automatic fire extinguishing system was activated in only one case, that being due to a delay in manual intervention.

There was no human intervention in the process during the time period when an increased number of fires were occurring in the relevant unit.

Support has been received from the machine manufacturer for ensuring the pressure balance between blowing and suction in the unit.

2.6. Environment factors

Production environment is kept constant between 20°-30° C in all seasons of the year using heaters and coolers.

Ignitions are generally occurring between March and November in Turkey. There are no cases in the summer. Flames occurred when the ambient humidity values were in the range of 17% -39%.

III. RESULTS AND DISCUSSION

Ignition sources while ethyl acetate contentration in between LEL-UEL and measures should be taken in printing machines' around or dryres are listed below briefly:

a- Flames : Cutting, welding, grinding etc… activities creates flame or sparks and can be the ignition source in explosive atmosphere. Therefore these kind of activities must not be done around printing unit while flamable gases and liquid are exist in working area.

b- Static electric : Static generation in pirinting machine might be stemmed from human, equipment, liquid and metarials such as cleaning rags, plastic bottles etc… Mearures to be taken to eliminate static electricity are ;

- work place should be clean, ink splah should be avoided, all solvent cubs should be closed and quantity of solvent should be minimised
- shoe foot test plates must be in place for employees to test their shoes for static dissipative properties daily
- employees' cloths should be made of fabric that will not produce static electric.
- any flammables at the press must be adeqautely grounded,testing regulalry is imperative. Earthing/grounding clamps must be clean and tested.
- machine body and machine parts must be grounded properly, be tested regularly
- work environment humidity should be appropreate with the product's insulation/conductivity charactaristics
- trolleys used for transporting flamable liquids must be clean with adequate grounding straps in place
- active and passive static neutralizers must be installed in the relevant machines to avoid static generation on film product and be tested regularly
- zero tolerance for plastics being used for flammable liquids. (I.E. buckets, jugs, cleaning containers such as floor mop buckets)
- solvent flow speed in pipe line should be limited to allow to disharge of static load according to relaxation time for each type of solvent

c- Friction : Friction can cause spark and over heating on machine parts. Additionaly over heating can reach a temperature which might be autoignition tempetature for solvents. Therefore all set-ups should be done properly, moving parts of machinery should be checked and heat controls must be done regularly. Tools which can create spark when contact with should be used in flamable atmosphere.

d- Electrical devices : Electrical equipment must be suitable for flammable atmosphere and tested regularly.

In this study he fuel source is the solvent vapor emitted at the entrance and middle part of the dryer tunnel. Although the average LEL value in the tunnel does not reach 100%, the measurement is taken by sampling the air in the dryer recirculation duct, which is a blend of air from all parts of the dryer tunnel.

This average does not adequately reflect the situation in the dryer, because the LEL value is not the same at every point of the tunnel. Also, there is a high concentration of ethyl acetate in the form of a thin layer at every point on the film surface.

As a result of the drying air blown at 110° C temperature, ethyl acetate will evaporate rapidly due to having a boiling point of 77° C. Due to the application of 5.8 grams per square meter of ethyl acetate on the film moving at 250 m / min, it was calculated that the concentration of ethyl acetate in air could be within the range 2%-11.5% (the LEL-UEL values for ethyl acetate), especially just after the entrance of the tunnel.

An ethyl acetate-air mixture at this concentration and temperature has an ignition energy of 0.46 mJ. If it encounters an energy source above this level it can easily be ignited. During the investigation of fire cases, the damage detected in the grate where the blowing nozzles at the entrance of the tunnel and the carbonization on its surface are proof that the flames started at the bottom of the tunnel [3] [4] [5] [6].

It must not be forgotten that, as the temperature in the dryer tunnel increases, the LEL% value at which ignition occurs decreases (Figure 5).

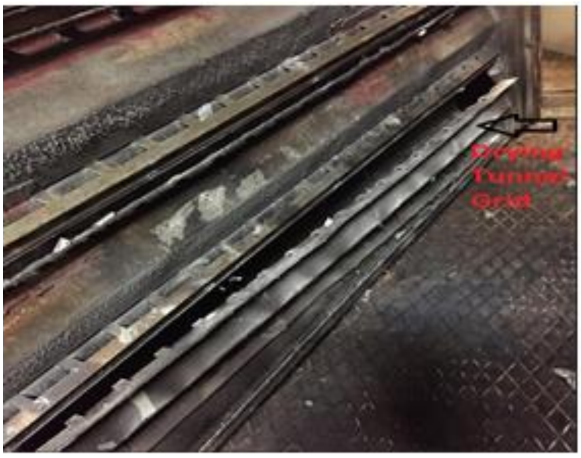


Figure 4. Damage and darkening of the dryer tunnel sub-grids after fire.

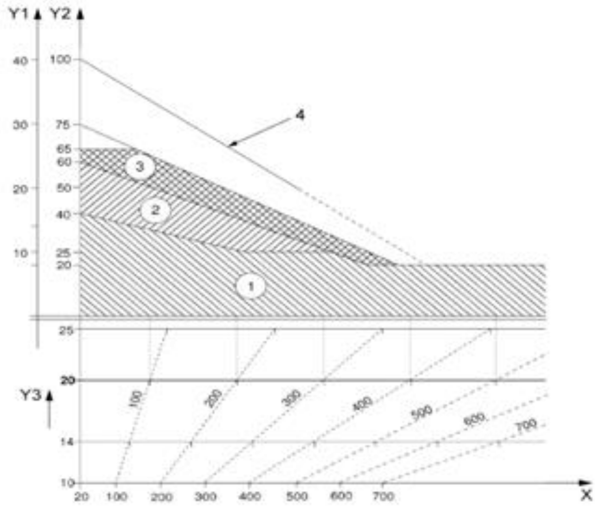


Figure 5. Maximum acceptable concentration and temperature values for inflammable substances

X) Maximum drying temperature

Y1) Concentration g / m³

Y2) LEL%

Y3) Δ LEL% / 100 K

The chart above (Fig. 5) is taken from the BS EN 1539:2015 standard for the design of dryers and ovens operating with substances that produce highly flammable/flammable gases. As can be understood from the graph, as the temperature increases in the environment with solvent vapor, the LEL% value required for explosion/flammability decreases. Since the starting point of the graph is 20 °C and at this temperature a solvent at 100% LEL level can reach the ignition level, when there is a temperature increase to 100 °C, ignitions can occur at 80% measured LEL [7].

In the trial studies carried out on the machine following the first fire incident, there was positive pressure in the tunnel. Flames became visible on the trolley some 2 seconds after the splice tape entered the tunnel, and this event occurred in the same way each time.

After ventilation adjustments were made to reduce the solvent concentration in the dryer tunnel, negative pressure was created in the tunnel. No fire was observed during the passage of the splice tail in on-site observations made under conditions of negative pressure.

However, under these conditions, fire incidents still occurred in the tunnel at various other times; these cases were investigated through video recordings made by the cameras available in the production area. In cases of negative pressure in the tunnel, the time for flames to spread out of the dryer extended and reached up to 27 seconds.

When there was positive pressure in the tunnel, each passage of a splice resulted in a fire; while with negative pressure in the tunnel both the frequency and intensity of fires decreased.

There is no evidence of friction that can create a heat source in the unit or dryer, and there is no electronic equipment in the tunnel that may cause a fire.

Since the static electricity voltage difference value measured on the film is zero, static electricity discharge due to the film itself was ruled out.

Fires occurred only during the splice. After the splice, a 40-50cm long tail is created. Fires also occurred when the tail's length was reduced to 10 cm by widening the tape area used for attaching the films to each other.Many electrostatic discharges may be the result of the accumulation of energy at individual points on a charged, non-conductive solid material, which may cause the initiation of ignition [6].

Fires occur only in processes where metallized OPP film is used as lamination material and the automatic splicing function of the machine is activated.

It has been observed that fires occur in the autumn and winter months when the humidity in the atmosphere is low, but not in the summer months, and moisture appears to be the main factor in the emergion of an ignition source resulting in the the conditions of a fire. Following this finding, a humidification system that will stabilize the humidity in the production environment at 50% and above in seasons when atmospheric humidity is low was installed in the production building. No ignition case was encountered in the period from 14.01.2020, which is the system's commissioning date, until the writing date of this article.

Figure 6. (7x0.17mm) Pulverized spraying equipment and pump assembly

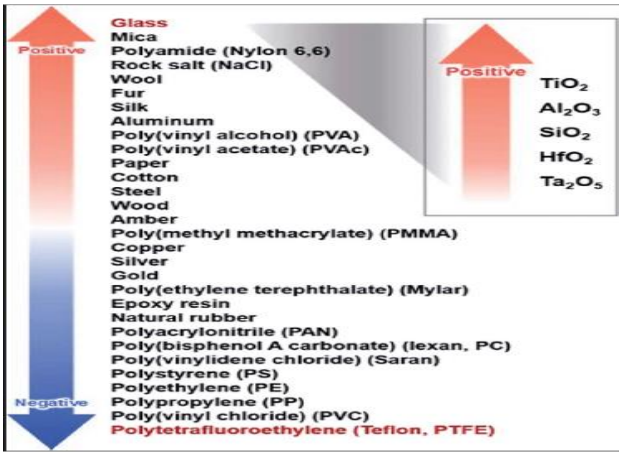
In addition to the conditioning system installed in the production environment, an atomized water spray system was installed in the 11th unit at the entrance of the first drying tunnel. This helped prevent the remaining 10 cm tail part from fluctuating while at the same time the conductivity of the film surface was increased. In addition, the ethyl acetate concentration at the tunnel entrance was further reduced.

For the system, the pump has a water spraying capacity of 1 liter per minute, feeding water to 5x0.15mm spray nozzles at the point where the film comes out of the nip between the impression roller and the application cylinder. The water spray from these nozzles helps to ensure surface conductivity. A further 2x0.15mm nozzles spray water to act as a barrier between the tail and the main film at the time of entering the tunnel, with an additional set of 5x0.15mm nozzles, intended to reduce the ethyl acetate concentration, installed at the tunnel entrance.

Friction and pressure occur in the tunnel between the OPP surface of the leading part of the splice tail, which tends to be negatively loaded, and the aluminum surface of the trailing part of the splice tail, which tends to be positively loaded. This situation causes electron transfer between the two materials. With the airflow effect in the tunnel, the two films are constantly and alternately brought into contact with each other and separated. Since the two films have different triboelectric properties, a static charge accumulates. Discharge occurs between the two materials when the charge is large enough to force the two layers to stabilize their charges. The static discharge created is considered to be the energy source of the fires that occurred [8].

Figure 7. Dryer tunnel inlet pulverized water spray system.

Table 2. Tribo Electric series



According to the results of the tests carried out by Bill W. Lee and David E. Orr, it is seen that the polypropylene film tends to be negatively charged during rubbing with the metallized surface in the triboelectric table. As a result of 1 Joule of frictional energy, 90 NC equivalent electron charge passes from metal to polypropylene, and the film is negatively charged [9].

IV. CONCLUSION

The relative humidity and temperature values of the production environment highly affect the mass and surface conductivity values of the materials. With environmental humidity, the surface resistance of many materials can be controlled. At 65% and higher relative humidity levels, many materials can absorb enough moisture to provide enough surface conductivity to prevent static electricity accumulation. The same materials at a humidity level of less than 30% become very good insulators and the accumulation of static electricity increases. Likewise, in an environment with humidity levels lower than 30%, the film becomes insulating and static electricity is charged. In the study, it was observed that no static discharge ocuured in between OPP and metallized OPP film as both metarials did not produce static discharge by gaining sufficient conductivity in a working environment with a relative humidity of 50% or more [10].

When the drying tunnels (which take their fresh air from the production environment), bring in ambient air at high humidity levels, the humidity of the air in the dryer will weaken the possibility of ethyl acetate reaching the LEL level required for ignition. In the observations made, it was observed that the average LEL value inside the tunnel was 22% in a production environment at 36% humidity and 20% in a production environment at 50% humidity.

The positive pressure in the dryer tunnel increases the possibility of fire due to the excessive concentration of solvent in the tunnel, increases the fire's intensity, and increases the possibility that the flames will rapidly exit from the tunnel to ignite the materials in the unit and its surroundings. Therefore, negative pressure should be created in tunnels where easily flammable materials such as ethyl acetate are dried and tunnel pressure should be checked regularly.

In products where metallized OPP film is used as a lamination material, the tail length should be zeroed or minimized as far as possible in order to prevent static accumlation and discharge.

Although the unit cost is higher and the energy requirement for its evaporation is higher compared to the solvent, water-based adhesive should be considered for use.

To prevent static electricity build-up on the film, grounding of machinery and equipment should be provided. Rotating equipment should have low surface and insulation resistance, and care should be taken to ensure that the oils used in bearings are conductive [6].

REFERENCES

[1] National Fire Protection Association (NFPA), “NFPA 30: Flammable and Combustible Liquid Code,” 2008 ed.

[2] Osterberg, Paul M., Niemeier, Jeffry K., Welch, Christopher J., Hawkins, Joel M., Martinelli, Joseph R., Johnson, Thomas E., Root, Thatcher W., Stahl, Shannon S. (2014). “Experimental Limiting Oxygen Concentrations for Nine Organic Solvents at Temperatures and Pressures Relevant to Aerobic Oxidations in the Pharmaceutical Industry ” Organic Process Research Development ACS Publications Special Issue: Oxidation and Oxidative Reactions” 19, 1537-1543, https://doi:10.1021/op500328f

[3] Bijay N. Pattanaik, Hiren C. Mandalia. (2011). Ethyl acetate: propertıes, productıon processes and applıcatıons. International Journal of Current Research and Review. Vol. 03 issue 12.

[4] European Solvents Industry Group. Flammability : A Safety Guide for Users- Safe Working with Industrial Solvents, Best Practice Guidelines no4 version3, June 2013.

[5] NFPA ® 497, Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas, 2008 Edition.

[6] Wiechula, B. M. (2013) The incendivity hazards of electrostatic discharges from charged, non-conductive solid materials. Review. Fire Safety Journal 60, 46-55.

[7] BS En 1539: 2015 Dryers and Ovens, in which Flammable Substances are Released- Safety Requirements. BSI Standartds Publication.

[8] Kim, Yeon Joo, Lee, Jaejun, Park, Sangwon, Park, Chanho, Park, Cheolmin, Choi, Heon-Jin (2017) “ Effect of the Relative Permittivity of Oxides on the Performance of TriboelectricNanogenerators” RSC Advances, 7, 49368, https://doi.10.1039/c7ra07274k

[9] Haiyyang Zou, Ying Zhang, Litong Guo, Peihong Wang, Xu He, Guzhang Dai, Haiwu Zheng, Choyu Chen, Aurelia Chi Wang,Cheng Xu, and Zhong Lin Wang. Quantifying the triboelectric series, Nat Commun. 2019; 10: 1427, https:// doi: 10.1038/s41467-019-09461-x

[10] NFPA ® 77, Recommended Practice on Static Electric, 2007 Edition.