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Project Report

Evaluation of Polymer Dispersed Liquid Crystal (PDLC) for Passive Rear Projection Screen Application

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Abstract

In the past few years, there have been many attempts to commercialize Polymer Dispersed Liquid Crystal (PDLC) for Rear Projection Screen (RPS) in electrically switchable films and glass products. This application is based on the exceptional image quality of PDLC at a wide viewing angle. However, due to the high price of conventional switchable PDLC privacy glass, the integration of RPS in PDLC failed to attract large multimedia and entertainment markets. An obvious solution to this problem is the independent development and evaluation of PDLC for Passive Rear Projection Screen (PRPS) application. However, in order to approve the application of PDLC for this purpose, further optical and image (visual) analyses are required. This work is the first part of our research project on evaluation of PDLC for RPS application, where we studied the effect of material and process parameters on optical properties of passive PDLC screens. The results indicate a strong dependence of the performances of passive PDLC screen on the material and process parameters, though it offers great advantages over conventional commercial RPS products. The second part of this study will focus on image evaluation of PDLC that will be the subject of a future study.

Keywords
PDLC; passive rear projection screen; optical evaluation; image qualification; application

1. Introduction

In the past three decades, the PDLC technology has captured vast interests in academic research and industrial development. The PDLC technology is the generic name for special two-phase composite systems consisting of a dispersion of micro and nanodroplets of liquid crystals into a polymer matrix for applications such as in large-area electrically switchable films, shutters, and windows.

The main concept of the research and industrial development of plastic PDLC technology lies in the stabilization of liquid crystals through their dispersions in a polymer matrix to manufacture large-area flexible Liquid Crystal Display (LCD) devices. This premise has resulted in the emergence of new technologies and products, among which PDLC has been the subject of most industrial interest and development in the past decade. However, since its development, the PDLC technology has found its way in commercial applications such as large-area “electrically-switchable” films and windows in architectural, building, residential, automotive, and other specialty markets.

Historically, J. L. Fergason invented PDLC by *micro-emulsion* (ME) technology [1], which was eventually licensed to Raychem Corp. (USA). Raychem commercialized it through Taliq and sub-licensed it to 3M, Asahi Glass, Nippon Sheet Glass, and Saint-Gobain in the early 1990s.

Independently in the late 1980s, J. W. Doane and coworkers at Kent State University (USA) patented the ‘PDLC’ technology by *phase separation* (PS) method [2]. The PS method offers a vast choice of UV-curable epoxy pre-polymers and thermoplastic polymers for PDLC processing. Eventually, owing to the limitations of working with ME, the PS method became extensively popular in both academic research and industrial development of PDLC devices.

The past three decades have witnessed a surge in academic literature and industrial activities in the field of PDLC technology. The industrial interest and progress in PDLC began only after the expiration of the main patents of Fergason-Raychem and Kent State University in 2002 and 2005, respectively. After this period, the PDLC industry has witnessed rapid progress by growing global demands. Currently, there exist over 15 PDLC film manufacturers and 100 PDLC glass processors worldwide.

There have been many studies on the different aspects of PDLC materials, their electro-optical properties, and preparation by micro-emulsion and phase separation methods [3-29]. However, these studies refer to lab-scale preparation of PDLC on glass supports with *standard* liquid crystal materials. On the other hand, at an industrial scale, the PDLC film is manufactured on large plastic supports by roll-to-roll techniques using different types of liquid crystal mixtures. The formulation and techniques to prepare the film at an industrial scale are not disclosed in the open literature. The readers, in order to know more about industrial development and historical evolution of PDLC technology, can refer to some earlier publications [30-37].

Due to the exceptional image quality of PDLC in projection screens, a number of commercial producers have integrated this application as part of the conventional privacy window products. Although PDLC supports both rear and front projections, most of the current switchable PDLC products incorporate only a Rear Projection Screen (RPS). The integration of RPS in active PDLC products has limited its application in the niche of smart glass market and, consequently, the technology could not make a place in much larger projection screen markets.

To the best of our knowledge, until now there has been no attempt to develop PDLC technology exclusively only for RPS applications. There have been only a few attempts in the literature to develop switchable PDLC technology for image display applications, including projection display light valve [38], pepper-ghost display [39], holographic display [40], image mode projection [41], high-definition TV [42], flexible LCD [43], and transparent projection screen [44].

However, despite its superior wide-angle image quality in the non-switchable state, except for our recent study [45], no attempts have been made to explore PDLC technology for PRPS applications. The main reasons for this lacuna are the unjustifiably high price of switchable PDLC for projection screen application and the lack of industrial initiatives for research, development, and commercialization of PRPS products with PDLC technology.

The evaluation of PDLC for its application in a PRPS requires combined quantitative optical and visual analyses. This could allow the development, scale-up, and production of new high quality, competitive, and low-cost PRPS products. In this article, we present the results of our preliminary study on the optical evaluation of a passive PDLC screen. The study includes the optical evaluation of our product and its comparison with a commercial RPS product. We further explored the effect of formulations, process parameters, thickness and viewing angle on the optical parameters of the fabricated passive (non-switchable) PDLC screen. The complementary image evaluation of the passive PDLC screen will be the subject of our subsequent work.

2. Experimental

2.1 Materials and the Preparation of the Passive PDLC Screen

The main materials utilized in this study were liquid crystals, UV-curable, and thermoset pre-polymers, photo-initiator, plastic micro-spacers, surface-treated PET, and ITO-PET film supports. The following liquid crystal mixtures were used: E7 (Hebei Pharmaceutical), UV-curable resin NOA65 pre-polymer (Norland Optical Adhesives), Irgacure 819 photo-initiator (BASF), plastic micro-spacer (Sekisui Chemical), in-house UV surface-treated PET films, and 100 Ω/θ ITO-PET films (Eastman Chemicals) with 175µm thickness.

All PDLC formulations and processes were carried out according to the standard procedure, where the components at corresponding concentrations were weighed, transferred into a vial and mixed for 3 h at a constant temperature of 40 °C. The uncured homogeneous PDLC mixtures were coated and laminated between ITO-coated or surface-treated PET films with a hand coater. The PDLC screens were cured either in a custom-made UV lamp on a conveyor belt at the intensity range of 31-166 mW/cm^2 and line speed range of 0.15-0.8 meter/min or in a thermal oven at 70 °C. The PDLC layer thicknesses were in a range of 5-30 µm. Further details of PDLC formulations and process parameters will be described in the corresponding sections of this work.

2.2 Measurements of Electro-Optical Properties

The electro-optical properties of PDLC films were determined by a custom-made Electro-Optical System (EOS), while PDLC morphologies were determined by a Quanta-200-FEG model Scanning Electron Microscope (SEM). The mixing and thermal properties of PDLC screens were studied by the Perkin Elmer DSC-6000 model Differential Scanning Calorimetry (DSC). The "total off-state transmission (T_{total}) was measured by BYK Hazegard-I and the "specular off-state transmission" (T_{min}) of PDLC screens as a function of angle were measured by a custom-made laboratory Electro-Optical System (EOS) setup.

2.3 Optical Benchmarking

In order to carry out a realistic optical evaluation of PDLC films, we selected three commercial Harkness projection screen products (Harkness Screens International Ltd, Dublin, Ireland) as a benchmark and, in order to compare their optical parameters with those of passive PDLC screens, we utilized the following normalized thickness equations:

$$\vartheta_{Harkness} = (T_{total}/T_{min}) / d_{Harkness} \quad (1)$$

$$\phi_{PDLC} = \{(T_{total}/T_{min}) \,.\, [2d_{PET} / (2d_{PET} + d_{PDLC})]\} / d_{PDLC} \quad (2)$$

The $\vartheta_{Harkness}$ and ϕ_{PDLC} (μm^{-1}) are the "normalized optical parameters" of Harkness and PDLC screens, respectively; T_{total} (%) is the "total forward off-state transmission"; T_{min} (%) is the "off-state specular transmission" of both screens and $d_{Harkness}$, d_{PET} and d_{PDLC} (µm) are their corresponding average thicknesses. The layout of T_{total} and T_{min} measurement system is presented in Figure 1.

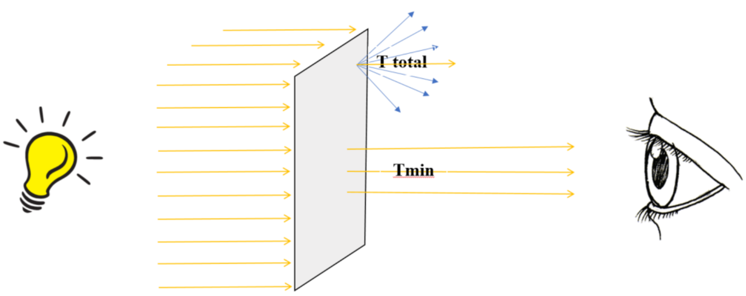

Figure 1 Illustration of T_{total} and T_{min} measurements.

The normalized optical parameters (namely, $\varphi_{Harkness}$, φ_{PDLC}, and T_{total}/T_{min} derived from Equations 1 and 2) offered a straightforward comparison and evaluation of passive PDLC screens against the Harkness screens. The rationale for measuring $\varphi_{Harkness}$ according to Equation 1 is that Harkness screen has a single layer, whereas φ_{PDLC} in Equation 2 is applicable for three layers that are normalized with two PET (or ITO-PET) support layers.

3. Optical Evaluation of Passive PDLC Screen

Accordingly, we evaluated PDLC screens by measuring their optical performances T_{total} and T_{min}, T_{total}/T_{min} and φ values as a function of material and process parameters, such as UV radiation intensity, photo-initiator, LC concentration, thickness, line speed, and viewing angle. The results of these studies are described in the following subsections. The optical parameters of all PDLC samples were calculated according to Equation 2.

3.1 Harkness Optical Performance

The selected Harkness Translite™ screens, which have been commercialized for both rear and front projections, are single layer screens with a thickness of around 300 µm. The optical parameters of three Harkness Translite™ screens as a benchmark are given in Table 1. The overall values of a normalized optical parameter of Harkness Translite screens are within ϑ=0.10-0.14 μm^{-1}, where Translite White has the highest value (ϑ=1.43 μm^{-1}) and Translite Grey has the lowest value (ϑ=0.097 μm^{-1}).

Table 1 Optical parameters of Harkness screens.

Harkness	**<d>** (µm) *	T_{total} (%)	T_{min} (%)	T_{total}/T_{min}	ϕ (μm^{-1}) **	**Projection**
Transite White	304	52.4	1.22	42.9	0.143	Rear / Front
Translie Grey	315	46.9	1.53	30.7	0.097	Rear
Translite Cream	295	57	1.63	35.0	0.119	Rear / Front
Translite Blue	315	29.7	0.69	43.0	0.137	Rear

* Harkness thickness <d> is an average of 12 measurements. ** Calculated from Equation -1.

3.2 The Effect of UV Intensity

We studied the effect of material and process parameters of making passive PDLC screen on the intensity of curing UV radiation at 31-166 mW/cm^2 for the following two PDLC formulations and process conditions of 25µm thickness and 0.15 and 0.30 meter/min line speeds:

E7-1: E7=53 %, NOA65=43%, Irga819=0.5%.

E7-24: E7=50%, NOA65=50%.

We measured the optical properties: T_{total}, T_{min}, and φ of these PDLC screens at *low* and *high* UV curing intensity ranges. In Tables 2 and 3, we provide the effect of UV intensities on the optical parameters of PDLC screens with E7-1 and E7-24 formulations, respectively. The φ values of these PDLC screens are in a range of 0.30-0.9 μm^{-1}, which are around 2-6 times higher than those of Harkness screens. We also noticed that E7-1 PDLC screen with a photo-initiator showed a strong *decreasing* trend of φ at *low* UV intensity range. Whereas, the E7-24 PDLC screen without the photo-initiator exhibited higher φ values but *the increasing* trend with the UV intensity. These data are plotted in Figure 2 for E7-1 and E7-24 PDLC screens at 0.15 and 0.30 m/min line speeds, respectively.

The smaller and decreasing trend of φ in E7-1 PDLC with photo-initiator resulted in lower T_{total} and higher T_{min} values. This means the accelerated matrix curing resulted in a decrease in LC droplet sizes and an increase in LC plasticization of the matrix. Whereas, the absence of photo-initiator in E-24 PDLC screen resulted in higher T_{total}, lower T_{min} and, consequently, larger φ and phase-separated LC droplets. A comparison between the two PDLC formulations indicated that passive E-24 PDLC screen with φ =0.90 at 0.15 m/min line speed is a more appropriate choice for PRPS application.

Table 2 Effect of low UV intensity on optical parameters of E7-1 PDLC screen.

I_{UV} (mW/cm^2)	S [m/min]	T_{total} (%)	T_{min} (%)	T_{total}/T_{min}	ϕ (μm^{-1}) *
31	0.15	60.7	2.8	21.8	0.77
66	0.15	59.9	4.1	14.8	0.52
126	0.15	59.3	6.5	9.1	0.32
31	0.3	60.3	3.5	17.2	0.61
66	0.3	59.4	4.5	13.2	0.46
126	0.3	59.2	5.5	10.8	0.38

* Calculated from Equation -2.

Table 3 Effect of high UV intensity on optical parameters of E7-24 PDLC screen.

I_{UV} (mW/cm^2)	S (m/min)	T_{total} (%)	T_{min} (%)	T_{total}/T_{min}	ϕ (μm^{-1}) *
113	0.15	71.7	2.91	24.6	0.86
135	0.15	70.6	2.85	24.8	0.87
148	0.15	70.5	2.83	24.9	0.88
166	0.15	70.2	2.76	25.4	0.90
113	0.3	70.1	3.05	23.0	0.81
135	0.3	69.5	2.98	23.3	0.82
148	0.3	69.3	2.96	23.4	0.83
166	0.3	68.7	2.67	24.9	0.88

* Calculated from Equation -2.

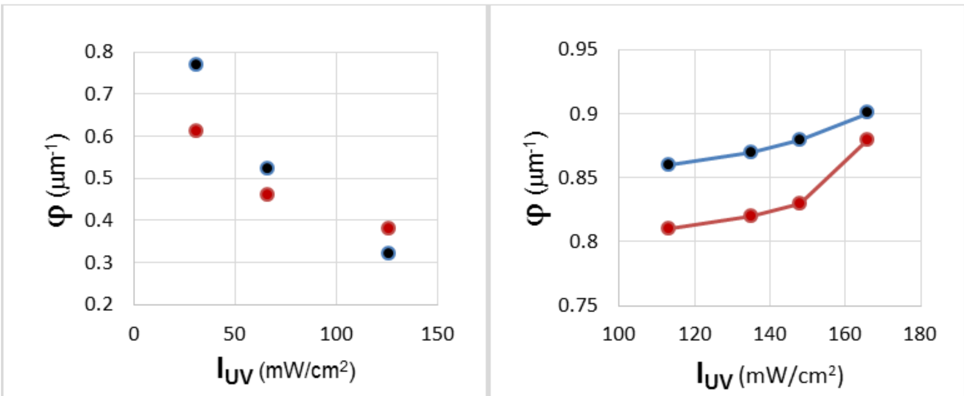

Figure 2 Effect of UV intensities on ϕ values of E7-1 (left) and E7-24 (right) PDLC at 0.15 m/min (black dots) and 0.30 m/min (red dots) line speeds.

3.3 The Effect of LC Concentration

The effect of LC concentration on optical parameters of passive PDLC screens was studied with liquid crystal mixtures E7 in a high concentration range. The PDLC screens utilized for this purpose consisted of the following formulations at *high* LC concentrations and process conditions:

E7-15*: (53, 57, 65, 75%), NOA65 (43, 39, 31, 21%), Irga819 (2%), and 25μm spacer (2.0 %).*

The PDLC screen formulations E7-15 in the 53-75% LC concentration range were prepared by weighing and mixing the corresponding amount of E7, NOA65 UV-curable resin, Irga819 photo-initiators, and micro-spacers. After coating of uncured mixture between ITO-PET supports, the screens were cured under the UV Intensity of 166 mW/cm^2 and a line speed of 0.15 m/min. The effects of LC concentration on the optical parameters of PDLC screens within E7 at 53–75% range are illustrated in Table 4.

Table 4 Effect of LC concentration on optical parameters of E7 15-18 PDLC screen.

E7-15 [%]	T_{total} [%]	T_{min} [%]	T_{total} / T_{min}	ϕ (μm^{-1}) *
53	77.4	3.8	20.4	0.72
57	76.2	4.7	16.2	0.57
65	75.6	6.1	12.4	0.44
75	78.3	7.5	10.4	0.37

* Calculated from Equation -2.

In general, the optical performance of PDLC at a high LC concentration range as in E7-15 formulations (see Table 4) resulted in a typically low T_{total} and high T_{min} values due to large micro-droplet dimensions. By increasing the LC loading, the micro-droplet sizes keep increasing and T_{total} and T_{min} tend to decrease. The outcome is evident by the dependency of the optical parameters of the E7-15 screens on LC concentration (see Table 4). In this regards, the *decreasing* trend of φ with E7 concentration in Figure 3 plot would be of particular interest in this PDLC screen, not only because of their larger values in comparison to Harkness screen, but because the PDLC screen at E7=53% with the largest φ value of 0.72 μm^{-1} would be the best choice of this formulation for PRPS application.

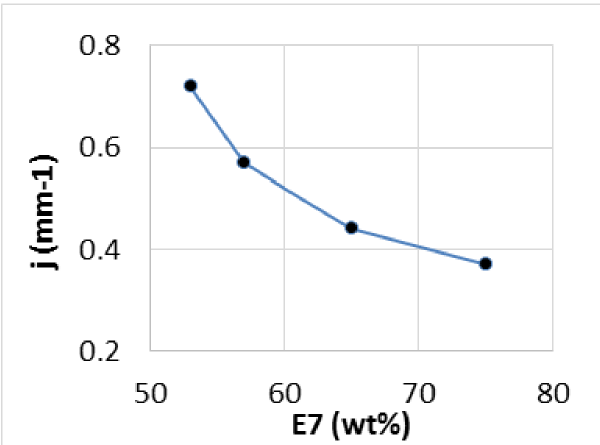

Figure 3 Angular dependence of ϕ values on concentrations for E7-15/PDLC screen.

3.4 The Effect of Thickness and Morphology

It is well known that the optical properties of PDLC films are significantly influenced by thickness and morphology. In this respect, we studied the effect of PDLC thickness and micro-droplet on optical parameters of the following three PDLC formulations:

E7-15: *E7 (53%), NOA65 (43%), Irga819 (2%),. UV=42.6mW/cm^2, S=0.15m/min, d=20, 30, 50 µm.*

***E7-24**: UV=113 mW/cm^2, S=0.15 m/min (see section 3.2), d = 25, 30 μm.*

***E7-19:** E7 (57%), NOA65 (39%), Irg819 (2%), UV=38mW/cm^2, S=0.30 m/min, d = 15, 20, 25, 30 μm.*

The optical parameters of E7-15, E7-24, and E7-19 PDLC screens as a function of thickness are given in Table 5. According to the table, in all three PDLC screens, the T_{total} and T_{min} values *decrease* along with an increase in the PDLC screen thickness. This is understandable, as the low values of T_{total} and T_{min} are the result of small sizes of micro-droplet morphologies of around 0.4-0.7μm and large droplet densities in PDLC screens. Generally, in thicker PDLC screens more light is absorbed, scattered, reflected, and less parallel light is able to go through the screen without interference.

Table 5 Effect of thickness on optical parameters of E7-15, E7-19, and E7-24 PDLC screens.

PDLC	**d** (μm)	T_{total} [%]	T_{min} [%]	T_{total}/T_{min}	**ϕ** (μm^{-1}) *
E7-15	20	66.3	5.3	12.5	0.56
E7-15	30	62.9	2.2	28.5	0.81
E7-15	50	54.7	1.66	32.9	0.51
E7-24	25	71.7	2.9	24.7	0.87
E7-24	30	70.8	2.4	29.5	0.84
E7-19	15	72.3	5.6	12.9	0.84
E7-19	20	71.5	3.6	19.9	0.89
E7-19	25	68.9	2.7	25.5	0.90
E7-19	30	66.7	2.1	31.8	0.90

* Calculated from Equation -2.

The effect of the thickness on ϕ values is illustrated for E7-19 PDLC screens in Figure 4, which indicate that φ *increases* with the thickness and reaches the maximum saturation level of φ= 0.90 μm^{-1} at 30 μm thickness. Therefore, the optical quality of E7-19 PDLC would be the most appropriate for a screen in PRPS application.

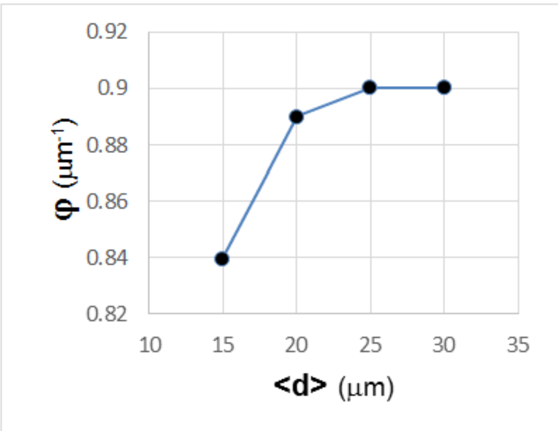

Figure 4 Effect of the thickness on ϕ values for E7-19 PDLC screen.

Furthermore, in order to investigate the effect of both thickness and morphology on optical parameters of PDLC screen, we carried out a more detailed study on the following thermoset PDLC formulation:

E7-20: *E7 (40%) Epon 828 (9.1%), Capcure 3-800 (33.8), Heloxy 5048 (17.1%) cured at 70 °C for 30 min.*

The effect of the thickness on morphology, including the micro-droplet dimensions (<D>), a fraction of phase-separated micro-droplets (<α>, as well as the optical parameters of E7-20 PDLC screens are given in Table 6. It can be seen that <D>, <α> and transmissions (T_{total} and T_{min}) *decrease* with the increasing PDLC thickness. At lower thickness range (5-10 µm), <D> values are within the 2.0-1.5 µm range but <α> remains almost constant. However, a rapid decrease in these parameters at a higher thickness range (15-25 µm) is mainly due to higher scattering that results from more material interacting with light, as well as slower phase separation, and faster matrix curing, leading to a higher matrix plasticization by liquid crystal (smaller <α>).

The examples of morphologies of E7-20 PDLC screens at 10 µm and 25 µm thickness are presented in the SEM micrographs (Figure 5).

Table 6 Effects of thickness and morphologies on optical parameters of E7-20 PDLC screen.

d (µm)	**<D>** (µm)	**<α>**	**T_{total}** (%)	**T_{min}** (%)	**T_{total}/T_{min}**	**ϕ** (μm^{-1}) *
5	2.1	0.46	93.5	3.4	27.5	5.3
7.5	1.8	0.47	89.5	1.7	52.6	6.7
10	1.4	0.46	85.0	0.9	94.4	8.9
15	1.0	0.29	79.5	1.1	72.3	4.4
25	0.6	0.16	60.0	1.2	50.0	1.8

* Calculated from Equation -2.

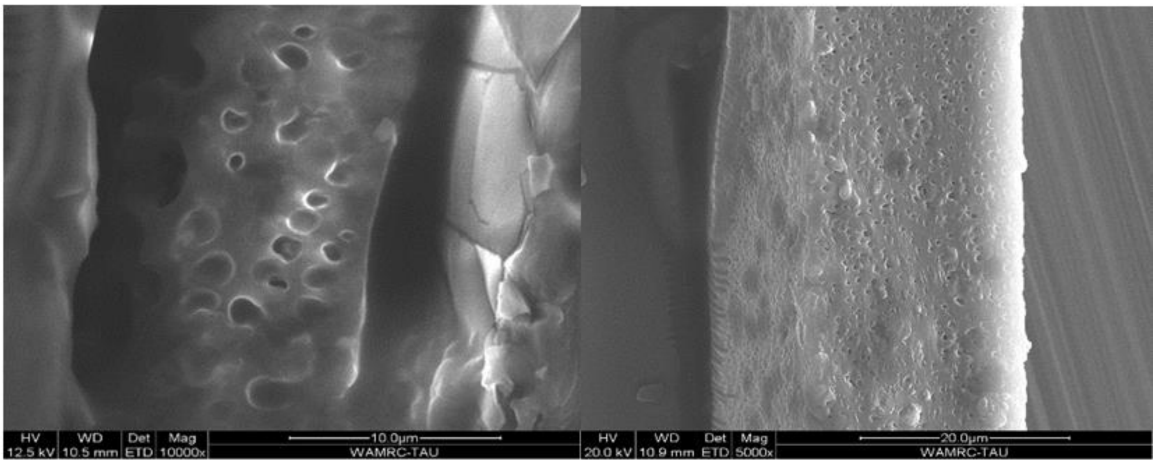

Figure 5 SEM images of E7-20 PDLC screens at 10 µm (left) and 25 µm (right) film thickness.

On the other hand, the ϕ values show a different trend with thickness. That is the dependency of ϕ with <d> and <D>, as plotted in Figure 6, i*ncreases* at lower <d> and higher <D> values, but *decreases* at higher <d> and lower <D> values. A perfect agreement between thickness and morphology plots can be seen, where both offer similar trends with a maximum value of ϕ=8.9 μm $^{-1}$ at <d>=10 μm and <D>=1.4 μm, which optically qualifies the E7-20/PDLC screen for PRPS application.

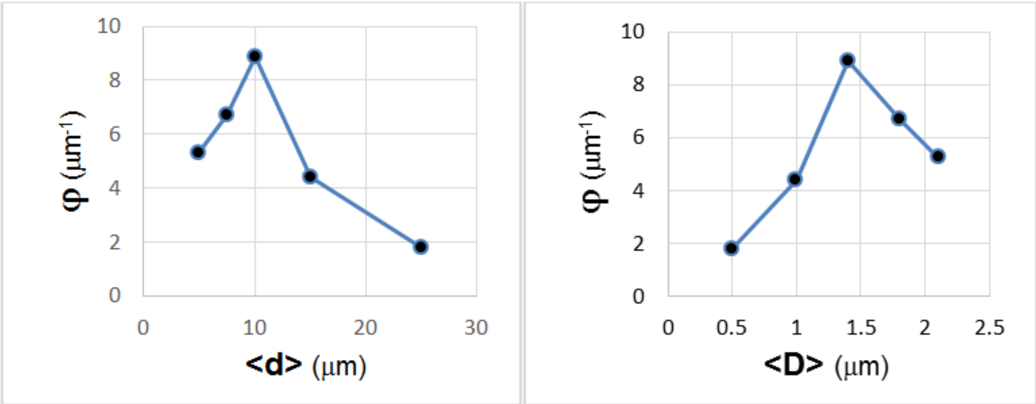

Figure 6 The effect of the thickness <d> (left) and droplet dimension <D> (right) on ϕ values in E7-20 PDLC.

3.5 The Effect of Line Speed

We studied the effect of processing line speed on optical parameters of PDLC screen with E7-1 formulation (see section 3.2) at UV intensities of 31 and 66 mW/cm^2 respectively and the results are presented in Table 7.

Table 7 Effect of line speed on optical parameters of E7-1 PDLC screen.

S [m/min]	I_{UV} [mW/cm^2]	T_{total} [%]	T_{min} [%]	T_{total} / T_{min}	ϕ (μm^{-1}) *
0.15	31	60.7	2.8	21.8	0.76
0.3	31	60.3	3.5	17.2	0.61
0.8	31	59.9	4.1	14.6	0.58
0.15	66	59.9	4.1	14.8	0.52
0.3	66	59.4	4.4	13.5	0.48
0.8	66	59.1	4.5	13.1	0.46

* Calculated from Equation -2.

It is evident that at both UV intensities, T_{total} *decreases* whereas T_{min} *increases* with line speed. The reason for these trends is that at high line speed, the matrix is not able to be cured and subsequently, the phase separation of micro-droplets becomes the dominant kinetic. This, in turn, results in the formation of larger droplets leading to higher T_{min} values. From Table 7, we also determined the ϕ parameter as a function of line speed. The result as plotted in Figure 7 indicates that at both UV intensities, ϕ *decreases* nonlinearly with the line speed. A comparison between two UV intensity regimes also confirms that curing at 31 mW/cm^2 provides larger ϕ values. Consequently, the E7-1/PDLC cured at S=0.15 m/min and UV=31 mW/cm^2 is the best screen qualified for PRPS application.

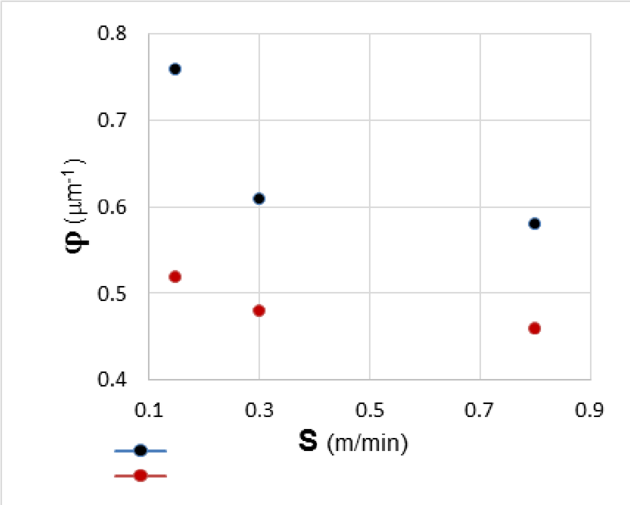

Figure 7 The effect of line speed on ϕ values of E7-1 PDLC screen at 31 (black dots) and 66 (red dots) mW/cm^2.

3.6 The Effect of Screen Angle

The optical measurement of "specular off-state transmission" T_{min} (see Figure 1) as a function of angle is a method that provides a quantitative clue on the visual quality of a screen. In this regard, we made a comparison between T_{min} values of PDLC and Harkness screens within an optical angle θ = 0-40 degree range. The results for Harkness and PDLC screens with E7-1 and E7-24 formulations at 25 μm thickness are given in Table 8, where the curing conditions are mentioned for each PDLC screen. As shown in the table, the angular dependence of T_{min} values of Harkness screens are within 1.6-0.9% range, whereas those of PDLC screens fall within 5.8-3.0%. This difference is mainly due to the higher thickness of Harkness screen (300 mm) than that of PDLC (25 μm) screens. In general, a lower value of T_{min} is preferable to reduce the amount of parallel light that passes through the screen. However, regardless of T_{min} values, its trend as a function of angle provides a measure of optical quality, which directly correlates with the visual quality of the screen.

Table 8 Angular dependence of T_{min} of E7-1 and E7-24 PDLC versus Harkness screens.

SCREEN	θ (deg)	**0**	**10**	**20**	**30**	**40**
Harkness		**T_{min}** (%)				
Translite White		1.58	1.52	1.39	1.23	1.03
Translite Grey		1.53	1.50	1.36	1.12	0.88
PDLC						
E7-1 (UV=31, S=0.3)		3.54	3.52	3.41	3.21	2.97
E7-1 (UV=126, S=0.3)		5.19	4.99	4.80	4.38	4.03
E7-1 (UV=166, S=0.3)		5.81	5.58	5.30	4.94	4.40
E7-24 (UV=113, S=0.15)		3.15	3.14	3.05	2.96	2.96
E7-24 (UV=166, S=0.8)		4.16	4.15	4.12	4.09	3.97

A comparison between the angular dependence of T_{min} of Harkness and PDLC screens (see Table 8) indicated contrasting trends. The angular dependence of T_{min} for E7-1 (UV=31, S=0.3) and E7-24 (UV=166, S=0.8) PDLC against Harkness White and Grey Translite screens are plotted in Figure 8. The T_{min} values in the figure are normalized with respect to T_{min}^{0} according to $T_{min} = 100xT_{min}^{\theta} / T_{min}^{0}$ relation. The results clearly demonstrate the superiority of optical quality of PDLC over Harkness screens at wide angles. Among the two PDLC screens, E7-24 PDLC with less angular dependence and higher ϕ value (see section 3.2) has the best optical output for PRPS application.

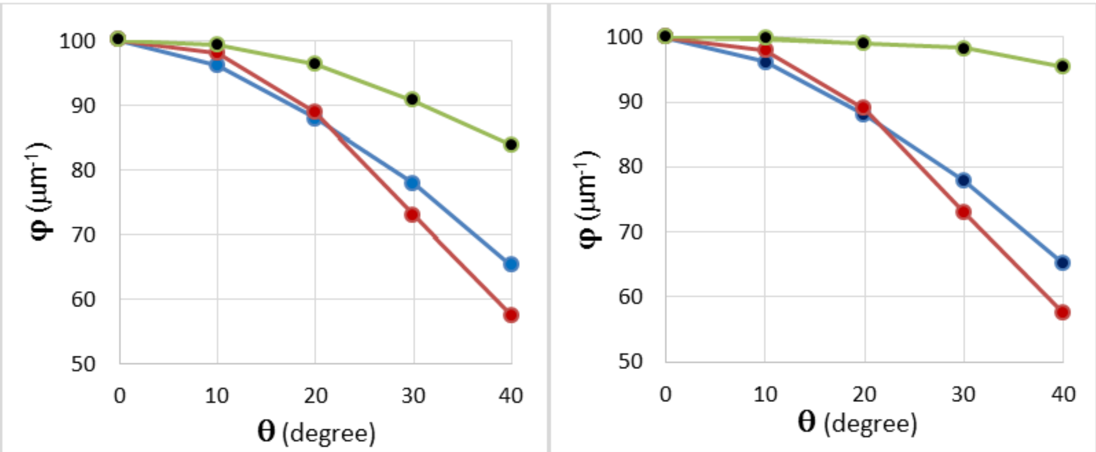

Figure 8 Angular dependence of T_{min} of E7-1 (left) and E7-24 (right) PDLC in comparison to Harkness screens. PDLC (black dots), White Translite (blue dots) and Grey Translite (red dots).

4. Conclusions

In this preliminary study, we evaluated passive PDLC films for application as a rear projection screen. The optical evaluation was carried out against a benchmark commercial projection screen. The aim of this study was to understand the effect of some material and process parameters on off-state transmissions T_{total}, T_{min}, and the "normalized optical parameter" ϕ of PDLC screens. Accordingly, we established empirical relations for PDLC evaluation and improvement.

We measured the optical parameters of various PDLC formulations as a function of UV intensity, line speed, LC concentration, thickness, micro-droplet dimensions, and screen angle. The results of the optical evaluation are as follows:

The magnitude of ϕ parameter for the PDLC screens is 2-10 times larger than commercial benchmark screens;

The variation of T_{min} with screen angle is much less in the PDLC screens than that in commercial screens. The optical parameters are sensitive to material and process conditions.

The relation between optical parameters and process conditions can be explored to improve PDLC in the application as a rear projection screen.

Accordingly, an optically qualified passive PDLC as an RPS should have high T_{total} and ϕ values, low T_{min} values, small angular dependence, micron-size LC droplet dimensions, and large micro-droplet number density.

The present study is the first attempt to evaluate passive PDLC for application as a rear projection screen, where we have applied an optical evaluation method. However, the complete evaluation for this application requires complementary image evaluation, which will be the subject of our future work.

Author Contributions

H. Hakemi, O. Pinshow, and D. Gal-Fuss did all the works.

Competing Interests

The authors have declared that no competing interests exist.

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