Winner of 2003 ANTEC Best Paper Award of the SPE Injection Molding!

New Intermeshing Pin (VIP) Mixer for Injection Molding

Chris Rauwendaal, Rauwendaal Extrusion Eng., Inc., Los Altos Hills, CA-USA
Rudolf Maurer, Sulzer Chemtech Ltd., Winterthur, Switzerland
Markus Scheuber, Sulzer Chemtech Ltd., Winterthur, Switzerland

Abstract

It is well known that reorientation of interfaces is key to efficient distributive mixing. However, how to achieve reorientation is not well known. This paper describes how interfaces can be reoriented in screw extruders and which method leads to the most effective reorientation. A new mixing device was developed to achieve highly efficient reorientation. This mixer can produce excellent mixing quality over a short axial length, as short as one diameter.

This makes it possible to incorporate this new mixer into the non-return valve of an injection molding screw. Results will be presented from injection molding studies that compare the mixing action of the new mixing non-return valve to other mixing devices.

Introduction

As injection molding machines (IMM) are used in more demanding applications the need for improved mixing capability becomes more important. This is particularly true for IMMs that blend virgin polymers with color concentrates (CC) or other master batches (MB) right at the feed throat of the plasticating unit, especially at low levels of CC or MB - less than about 3%. Considering that the length of plasticating units is quite short, typically 20D, it is important to incorporate very effective mixing devices that can achieve good mixing over a short distance. This is even more important because the effective length of the plasticating unit is shorter than its actual length because of the reciprocating action of the screw.

This paper will describe a new mixing device that can be incorporated into the non-return valve (NRV) located at the end of the screw. This mixer relies on the intermeshing action of pins or flight segments to achieve a very high level of reorientation of the interfaces. The intermeshing action of the pins creates circulatory flow patterns; as a result, the mixer is called the Vortex Intermeshing Pin (VIP) mixer. The ability of this mixer to achieve a very effective increase in the interfacial area gives it excellent distributive mixing capability.

Requirements for Effective Distributive Mixing

The quality of distributive mixing is often described by the increase in interfacial area or the reduction in striation thickness. In simple shear flow the striation thickness s is a simple function of the total shear strain γ (1).

$$\frac{s}{s_0} = \frac{1}{\sqrt{1+g^2}} \qquad (1)$$

Figure 1 shows the relationship between striation thickness and shear strain in graphical form. The striation thickness reduces quickly in the first 5-10 units of shear; however, at higher levels of shear strain the reduction in striation thickness occurs very slowly. Essentially, 90% of the reduction occurs in the first ten units of shear; shearing beyond this point is relatively ineffective.

The most effective method to retain the high initial mixing efficiency is to reorient the interfaces periodically along the mixing section. The effect of reorientation on striation thickness can be described as follows (2).

$$\frac{s_n(g_1)}{s_1(ng_1)} = \left(\frac{n}{0.5g_1}\right)^{n-1} \qquad (2)$$

where $s_n(\gamma_1)$ is the striation thickness after n exposures to shear strain γ_1 with reorientation after each exposure and $s_1(n\gamma_1)$ is the striation thickness after n exposures to shear strain γ_1 without any reorientation.

Figure 2 shows the relationship between striation thickness and shear strain showing the effect of reorientation. One reorientation event at a shear strain of 100 units reduces the striation thickness about 2 orders of magnitude after 1000 units of shear strain. Two reorientation events reduce the striation thickness by another 2 orders of magnitude, etc. Clearly, reorientation can dramatically increase mixing efficiency – it is the key to achieving effective distributive mixing.

Methods of Achieving Effective Reorientation

Simple conveying screws are rather ineffective in reorienting the interfaces. As a result, they have poor mixing capability. Many modifications to the standard screw geometry have been made to improve the mixing capability of extruder screws. There are literally thousands of mixing devices with varying levels of mixing efficiency. It is well recognized that mixing elements with multiple flights with slots machined into the flights can achieve effective distributive mixing. Examples of these mixers are the Dulmage mixer, the Saxton mixer, and the CRD mixer.

The multiple flights are useful in mixing because they split the flow from a single channel into multiple channels. The slots are beneficial in that they allow the polymer melt from one channel to flow into an adjacent channel. As a result, the slots enhance both the mixing action and the heat transfer between the barrel and the polymer melt. Unfortunately, slotted multi-flighted mixers may not provide sufficient mixing capability for the more demanding applications. Therefore, there is a need to develop a mixer geometry that improves mixing beyond that of slotted multi-flighted mixers.

One of the most effective means of increasing interfacial area is a stretching and folding of the interfaces. This is well known from studies on chaotic mixing. The practical question is how we can achieve stretching and folding of the interfaces in a screw extrusion device. The most effective method is to use active mixing elements both on the screw and the barrel. In fact, there are a number of commercial mixing devices that use this principle. An example is the Buss Kneader (3) developed about half a century ago and still commercially available. The Kneader is a single screw extruder with multiple slotted flights and three rows of barrel pins. The screw rotates and reciprocates so that the barrel pins move through the slots in the screw flights, see figure 3. The highly effective mixing action of the kneader allows a very short machine length, typically about 11D. Compare this to a typical length of 30D-50D for twin screw compounding extruder (TSCE) and it becomes clear that the mixing efficiency of a kneader per unit axial length is substantially better than both single and twin screw extruders.

The drawback of most extruders with active barrel mixing elements is that they are complicated in design, expensive to manufacture, and difficult to operate and clean. The challenge is to find a method to have active mixing elements interacting with the screw without complicating the design and operation of the extruder. The answer to this challenge is the method developed at Twente University in Enschede, the Netherlands (4) to incorporate a floating ring or sleeve between the screw and the barrel. The Twente Mixing Ring (TMR) was the first mixer developed with a floating ring. The TMR is basically a simplified version of the cavity transfer mixer (CTM) developed at RAPRA (5).

Figure 4 shows the TMR. It has hemi-spherical cavities in the screw and circular holes in the floating sleeve. It achieves good mixing action; however, it has no mechanism for active folding and stretching because there is no intermeshing action between the screw and sleeve elements. A new mixing device was developed to combine the best features of a sleeve mixer with the best features of intermeshing pin barrel extruders. The intermeshing action of the pins of this new mixer creates circulatory flow patterns; as a result, the mixer is called the Vortex Intermeshing Pin (VIP) mixer. The benefit of this approach is that very effective mixing can be achieved over a very short distance while the barrel has a conventional design. As a result, the mixing device is easy to manufacture, simple to install, easy to run, and quick and easy to clean.

Description of the VIP mixer

The VIP mixer (6) is equipped with a floating sleeve; the sleeve rotates with the screw but at a lower rotational speed. As a result, there is a relative motion between the screw and the mixing sleeve that is critical to the effective mixing action. Figure 5 shows an example of the VIP mixer. The screw has multiple flights with circumferential slots machined into the flights. The sleeve is equipped with mixing pins that protrude radially inward. As a result, the pins fully intermesh with the screw flights.

The intermeshing action and the relative velocity between the pinned sleeve and the screw provides an effective stretching and folding action in a regular screw extruder or injection molding plasticating unit. This action is similar to that of a rake. Figure 6 schematically illustrates the stretching and folding action of the VIP mixer.

In the absence of moving pins the flow path is not materially altered as a fluid element crosses the groove region of the mixer. However, with moving pins the fluid elements are pushed and dragged in circumferential direction. This causes reorientation and stretching of the interfaces which greatly increases the effectiveness of mixing. The pins also cause a folding of the flow paths around the pins further increasing mixing effectiveness.

It is interesting to note that the intermeshing action between the pins on the sleeve and the screw occurs over the entire circumference of the screw. This results in a very effective mixing action. In twin screw extruders, on the other hand, the intermeshing action occurs only over a small fraction of the circumference, less than one-fourth. This is illustrated in figure 7 that shows a twin screw extruder with pin shaped mixing elements on the screw (left) and a single screw extruder with pin shaped mixing elements on both the screw and the sleeve. In the twin screw extruder there is limited interaction between the pin shaped mixing elements indicated by the colored intermeshing region. In the single screw mixer there is complete interaction between the pin shaped mixing elements of the screw and sleeve. As a result, the mixing action of the VIP mixer is considerably more efficient than pin shaped mixing elements in a twin screw extruder.

The same argument explains why the Buss Kneader is more efficient in mixing than a twin screw extruder. The Kneader has only three pins around the circumference; the VIP mixer can have eight or more pins around the circumference. A greater number of pins results in improved mixing action.

Experimental results

The VIP mixer was incorporated into a non-return valve (NRV) and tested on an injection molding machine (IMM). The mixer was tested by changing color and evaluating the molded plaques through the transition from one color to another. The resin used in the experiments was a transparent ABS supplied by the company Goldmann; the color masterbatch was a 2% red supplied by the company Finke. The IMM was a 40-ton Engel ES 200/40 with a screw diameter of 30-mm.

The mold was a two-plaque mold with plaque dimensions of 78 x 58 mm and plaque thickness of 3 mm. Each plaque has one square hole 16 x 16 mm and one circular hole with a 16 mm diameter. Each plaque also has two blind holes with a diameter of 16 mm; one hole has a depth of 1.0 mm and the other a depth of 1.9 mm resulting in a wall thickness of 2.0 and 1.1 mm, resp. This thin-walled region is useful in assessing the color distribution because streaks can be easily observed with a light source placed behind the thin-walled region. It is more difficult to assess the color distribution in the thick-walled section because light does not easily penetrate the 3 mm thick section.

The following test procedure was used. First, the IMM was started with natural polymer. After steady conditions were achieved the red material was introduced to the machine. After the color change it took a number of shots before the color no longer changed in the molded plaques; this number was counted and recorded. Beyond this point several more colored plaques were molded and checked for color uniformity and dispersion. At this point, the material was changed again to natural and the number of shots were counted to achieve a completely color free product.

In the experiments a standard slide ring NRV was compared to a VIP NRV. In switching from natural to red it took 6 to 8 shots with the STD NRV to achieve consistent color from plaque to plaque while it took 3 to 4 shots with the VIP NRV. The color distribution with the STD NRV was rather poor with noticeable streaks and swirls in the plaques. The color distribution with the VIP NRV was quite uniform without any streaks or swirls. In switching from red to natural it took more than 30 shots with the STD NRV for the plaques to be color free - small streaks could still be observed. With the VIP NRV it took about 20 shots for the red color to disappear completely without any streaks in the product.

The experimental results indicate that color changes can be made more rapidly with the VIP-NRV as compared to the STD-NRV; the results are summarized in figure 8. The result confirm that a color change from natural to a dark color occurs much more rapidly than a color change from dark to natural. Further, the mixing capability of the VIP-NRV is substantially improved over the STD-NRV as determined by analyzing the color uniformity in the molded plaques.

Figure 9 shows a representative sample of a plaque made with a standard NRV during the transition from red to natural. The figure clearly shows how the red material displaces the natural material. Figure 10 shows a complete stack of plaques obtained before, during, and after switching from natural to red and back to natural with the VIP-NRV. The color change from red to natural took about 20 shots. Figure 11 shows a complete stack of plaques with color changes obtained with the STD-NRV. The color change from red to natural took more than 30 shots as illustrated in a bar chart in figure 8.

Conclusions

The effectiveness of the mixing action in the VIP mixer is due to the active stretching and folding of the interfaces achieved by the intermeshing action of the pins into the screw flights and the relative motion between the pins and the screw. As a result, effective mixing can be achieved over a short distance. This makes the VIP mixer ideal for incorporation into an injection molding non-return valve. The VIP-NRV provides both mixing and shut-off action and it fits in the same space as a conventional NRV. However, the applications for the VIP mixer are not limited to injection molding.

These mixers can be used in extrusion, compounding, direct-extrusion, foam extrusion, blow molding, and direct-injection molding. The VIP mixer fits in a conventional smooth barrel and, therefore, can be used in standard extruders and injection molding machines. Installation of the VIP mixer does not require modification of the extruder barrel or a barrel extension. As a result, installation is simple and straightforward.

References

1. Mohr, W.D., Saxton, R.L., Jepson, C.H., Ind. Eng. Chem. (1957), 49, p. 1855
2. Erwin, L., in "Mixing in Polymer Processing," Rauwendaal, C., Editor, Marcel Dekker, New York, (1991), Chapter 1 "Principles of Laminar Fluid/Fluid Mixing," p. 1-16
3. Case, C.C., in "Polymer Mixing, Technology and Engineering," White, J.L., Coran, A.Y., Moet, A., Editors, Carl Hanser Verlag, Munich, (2001), Chapter 5, "Kneaders," p. 102-118
4. Semmekrot, G., U.S. Patent 5,013,233 (1991)
5. Gale, G.M. and Hindmarch, R.S., European Rubber Journal, July-August (1982), p. 29
6. Rauwendaal, C.J., (2002), U.S. Patent pending

Keywords: mixing, VIP mixer, striation thickness, reorientation, non-return valve

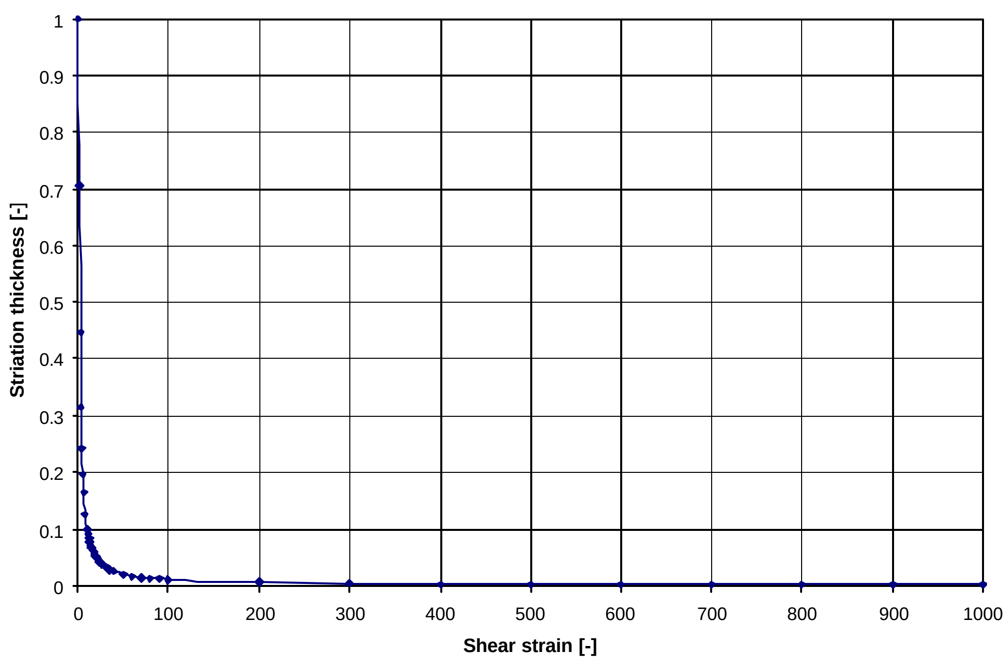

Figure 1, Striation thickness versus shear strain

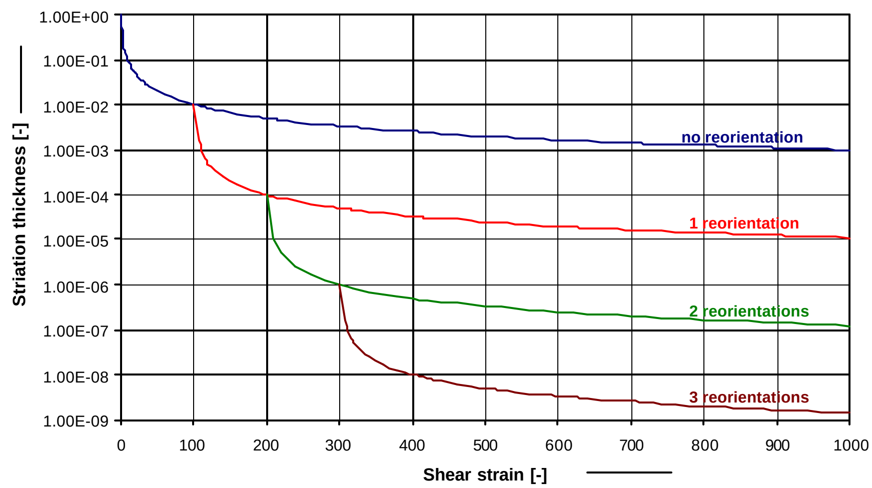

Figure 2, Striation thickness versus shear strain with reorientation

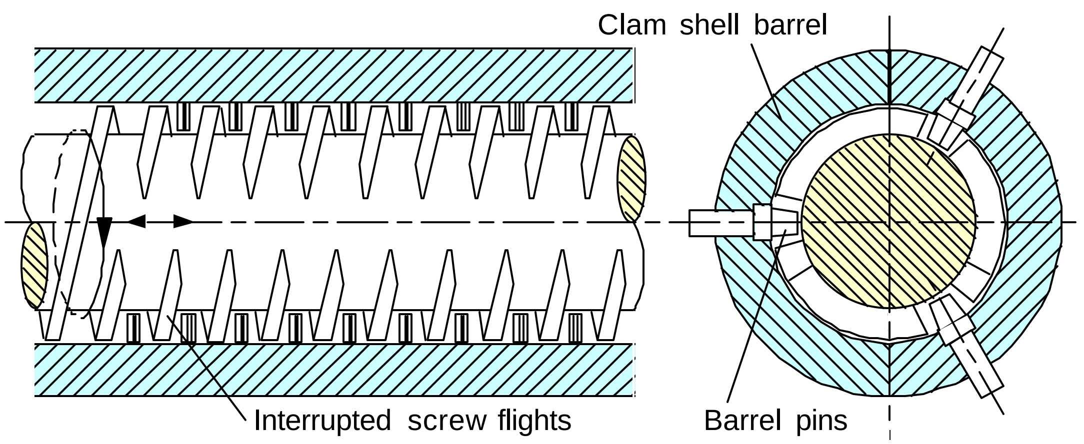

Figure 3, Schematic of the Buss Kneader

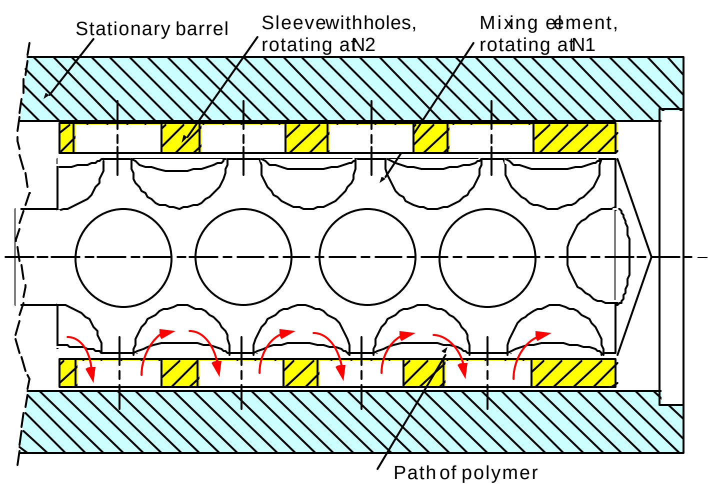

Figure 4, Representation of the Twente Mixing Ring

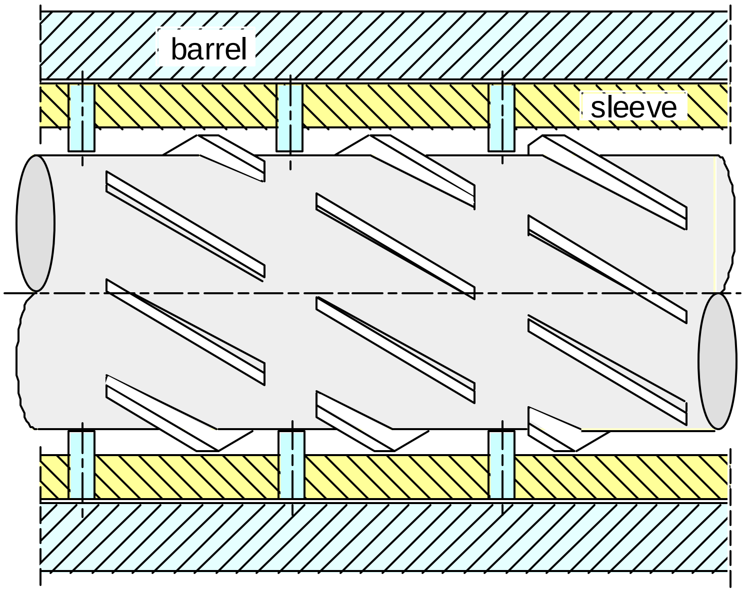

Figure 5, VIP mixer

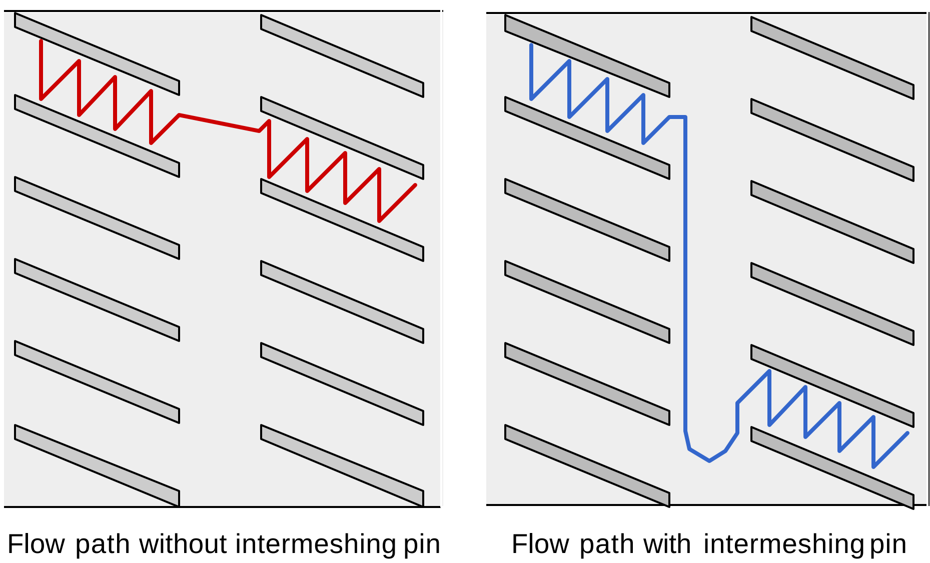

Figure 6, Stretching and folding action in the VIP mixer

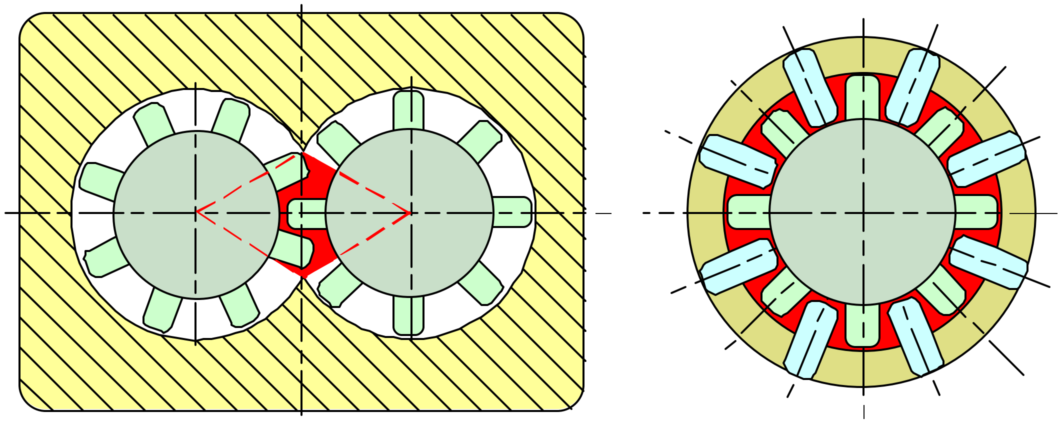

Figure 7, Intermeshing region in twin screw extruder (left) and in VIP mixer (right)

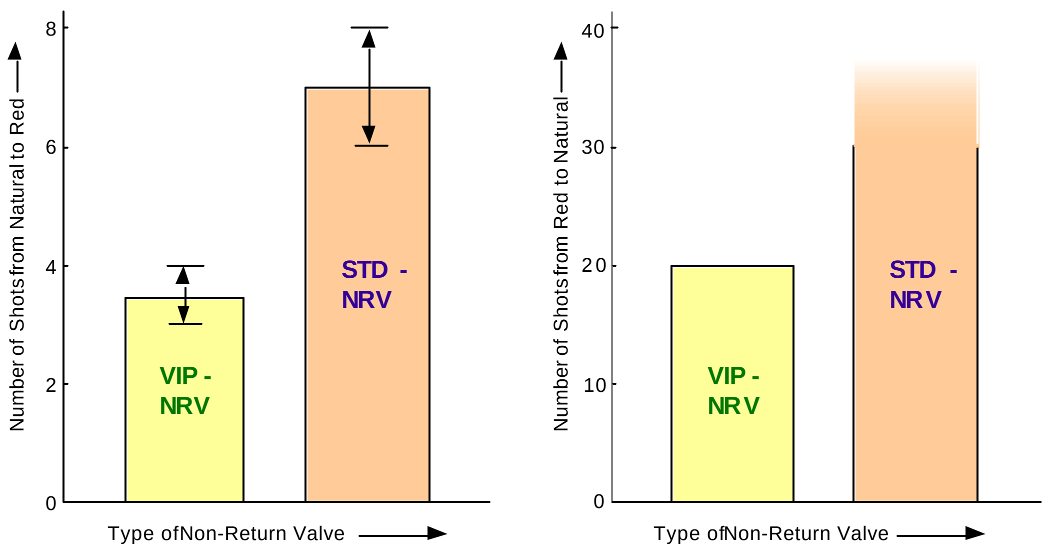

Figure 8, Number of shots for color change for VIP-NRV and STD-NRV

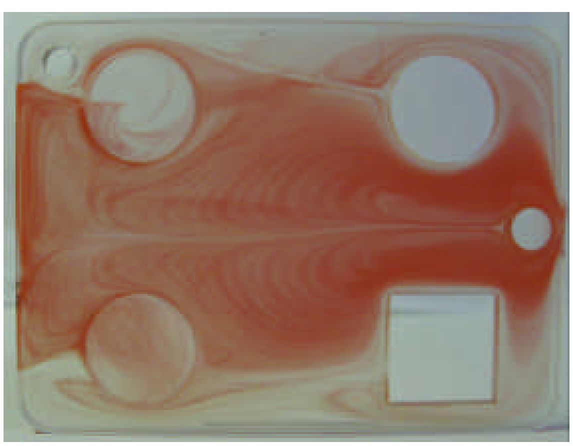

Figure 9, Transition from natural to red for STD-NRV

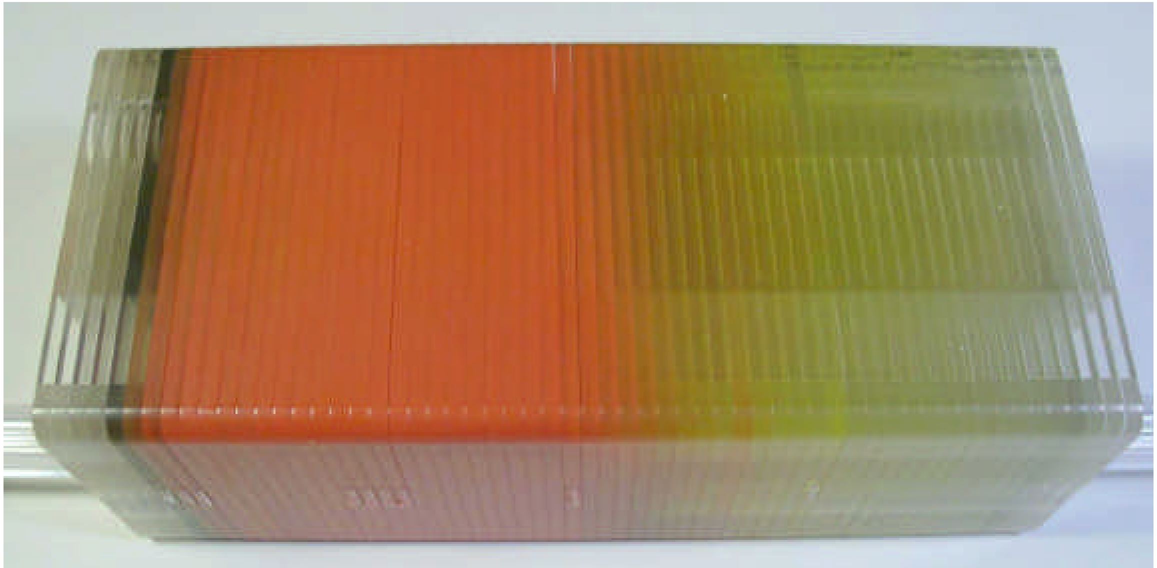

Figure 10, Complete stack of plaques showing the color changeover with the VIP-NRV

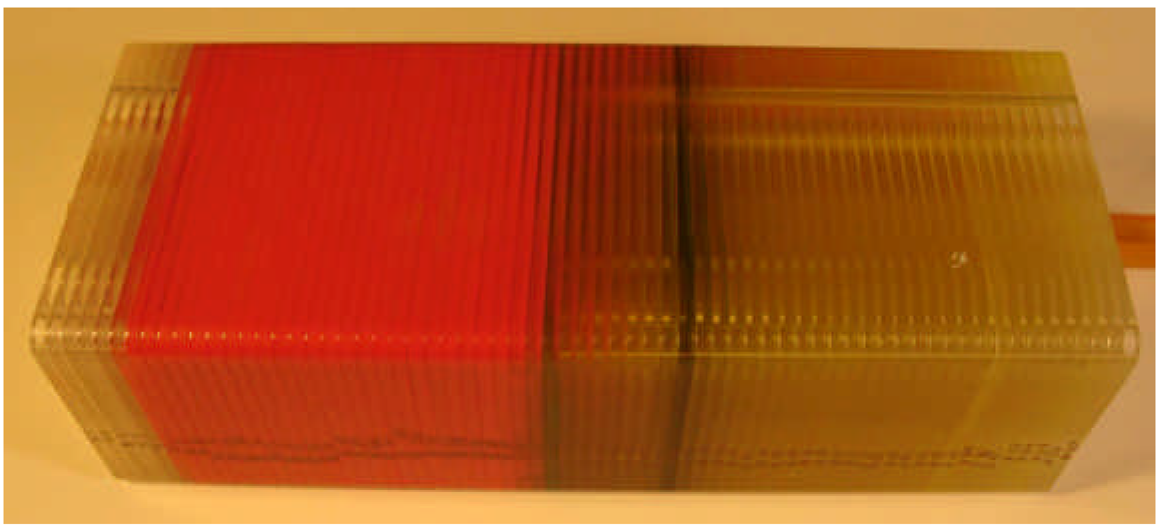

Figure 11, Complete stack of plaques showing the color changeover with the STD-NRV