

Specifically, as  $d_2/d_1$  increases (i.e., above critical layer depth ratio) so does the growth rates. Furthermore it is clear from this figure that the maximum growth rate for all layer depth ratios is around dimensionless wave number of unity.

As this figure indicates the magnitude of growth rates are a function of layer depth ratio.

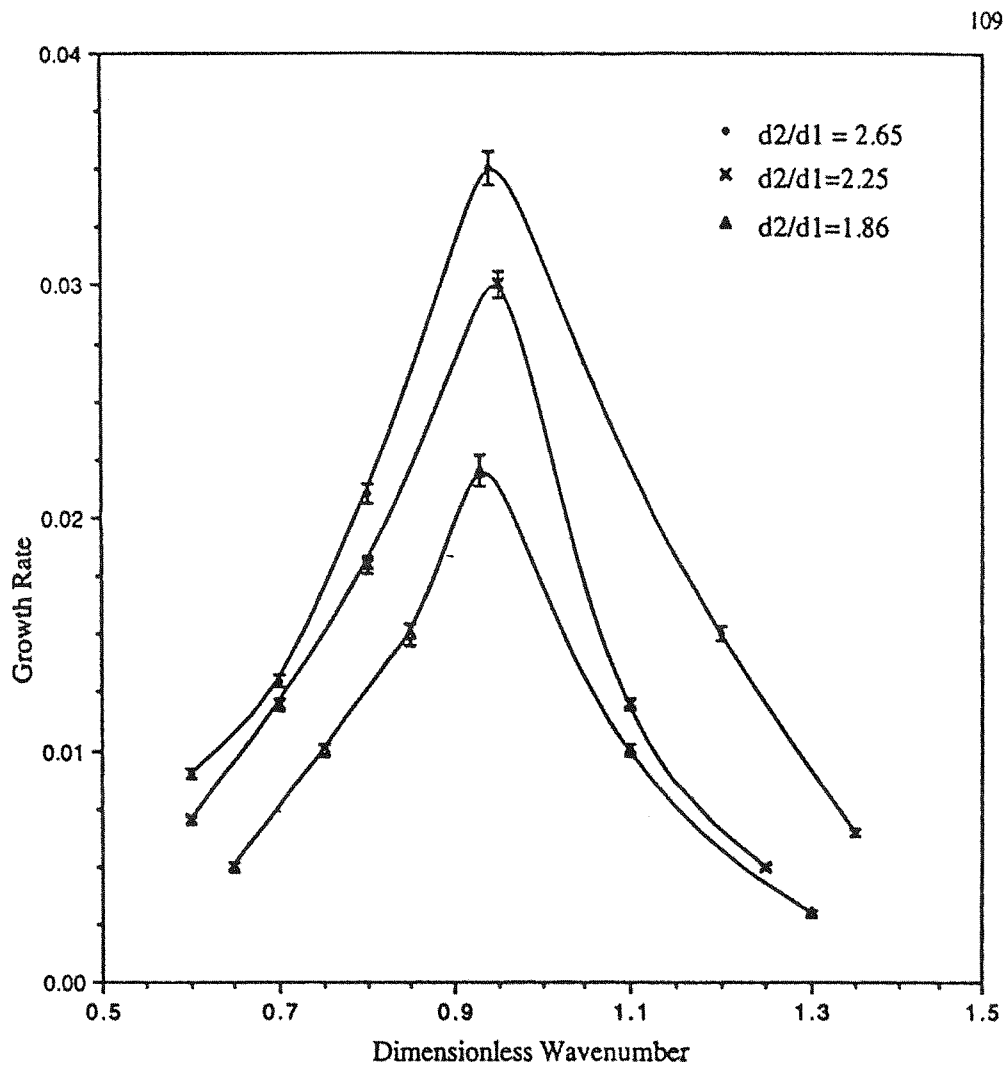


Figure (5).

### References

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we can not determine the stability of the system for the same reason mentioned above for long wave disturbances. Figure 5. shows the measured growth rates for this polymer system.

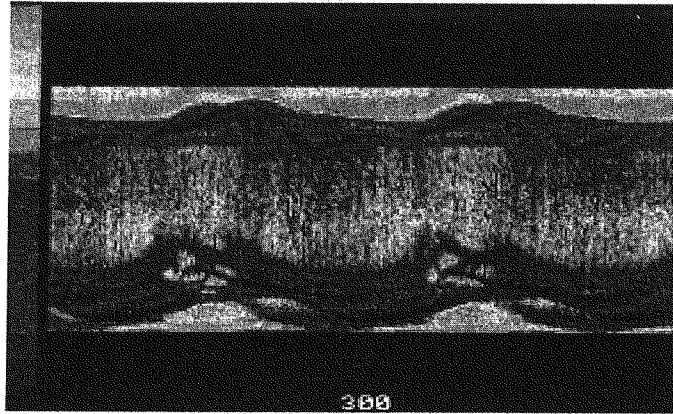


Figure (3).

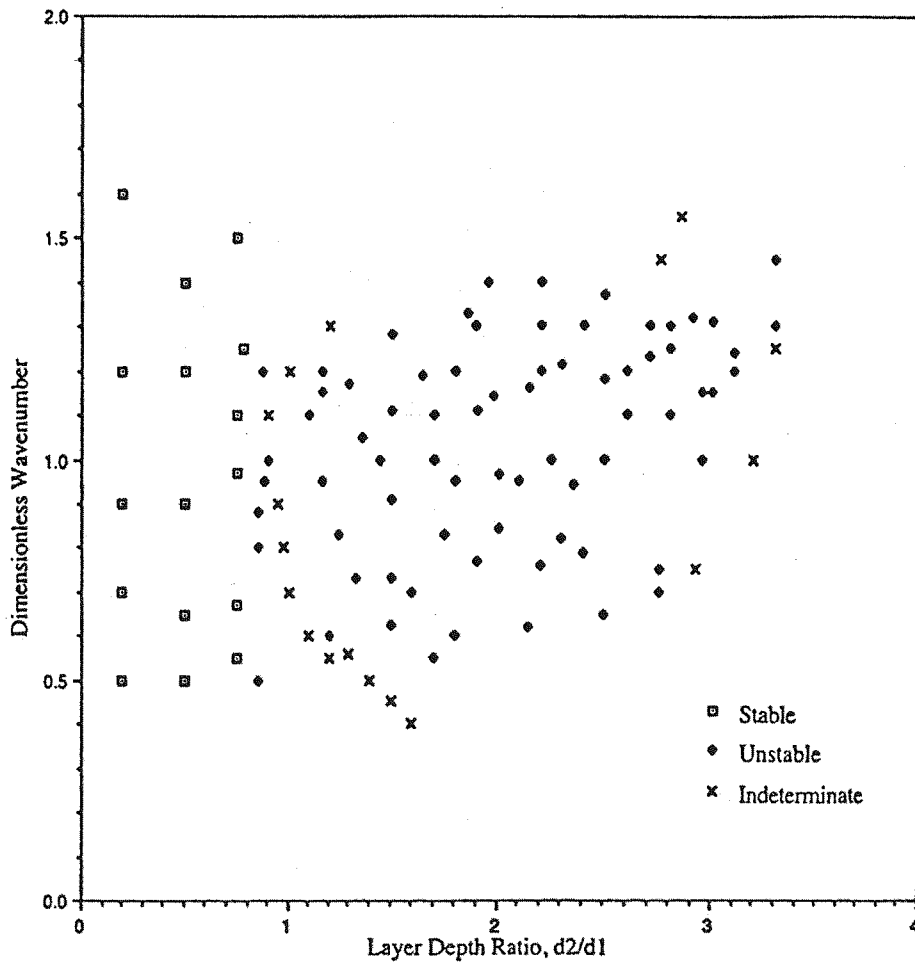


Figure (4).

train shown in Figure 1 is typical of that used in experimental study and consists of a high intensity light source and fiber-optic cable guide, a 559.8 nm filter and an achromatic lens. The optical components and video camera are mounted on a standard cast iron bench, which is itself mounted on a motor driven stage. The analog signal from the video camera is simultaneously sent to a S-VHS VCR. The images from either the image board or the VCR are displaced on a high resolution RGB monitor.

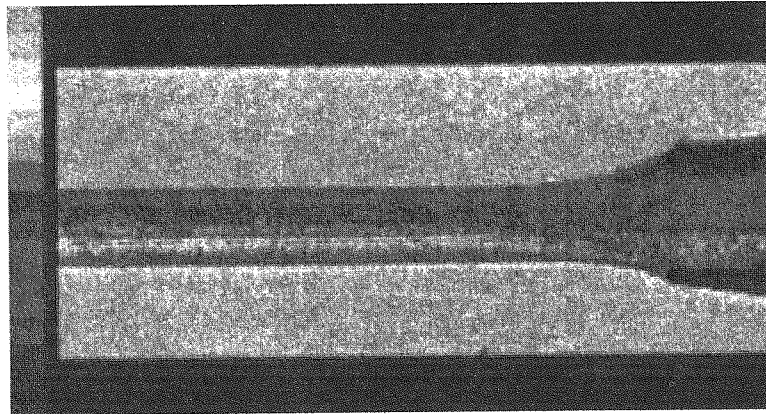


Figure (2).

### **Entrance flow**

As clearly shown by figure 2. The entrance length is a strong function of both the nature of the flow as well as the operating condition (i.e, flow rates and their ratios). By carefully analyzing the entrance flow regime, the region in which the flow becomes that of fully developed superposed flow between two parallel plates can be determined. In turn velocity profiles can be measured in the region.

### **PP/HDPE/PP Experiments**

In these experiments, the instability is observed and measured with the aid of digital image processing techniques. Based on these experiments, we have constructed stability contours and growth decay rate plots that clearly demonstrate the effect of various important parameters (i.e. layer depth ratio, viscosity ratio and elasticity ratio) on the stability of the interface as well as the growth rate of various disturbances.

### **Stability Results and Discussion**

Composite image of an unstable flow is shown Figure 3. The images was generated from 20 seconds video at  $x = 5$  cm downstream position.

The stability contour graph is shown in Figure 4. As Figure 4 indicates it appears that a critical ratio ( $d = 0.85$ ) exists below which flow is stable and above which is unstable. Specifically, when  $d_2/d_1$  is less than the critical value the flow is stable to all intermediate and shortwave disturbances (i.e, because of the combination of encapsulation and entrance effects as well as very small growth or decay rate of longwave disturbances, the stability of the flow to these disturbances can not be accurately determined), while at  $d_2/d_1$  greater than the critical layer depth ratio the unstable region strongly depends on the disturbances wave number. Specifically, the flow is unstable to intermediate wave number, while at short-wave

involved (i.e., layer depth ratio viscosity, elasticity) and their probable contribution to the overall stability of the flow. The experiments targeted flow configuration, namely A-B-A symmetric flows.

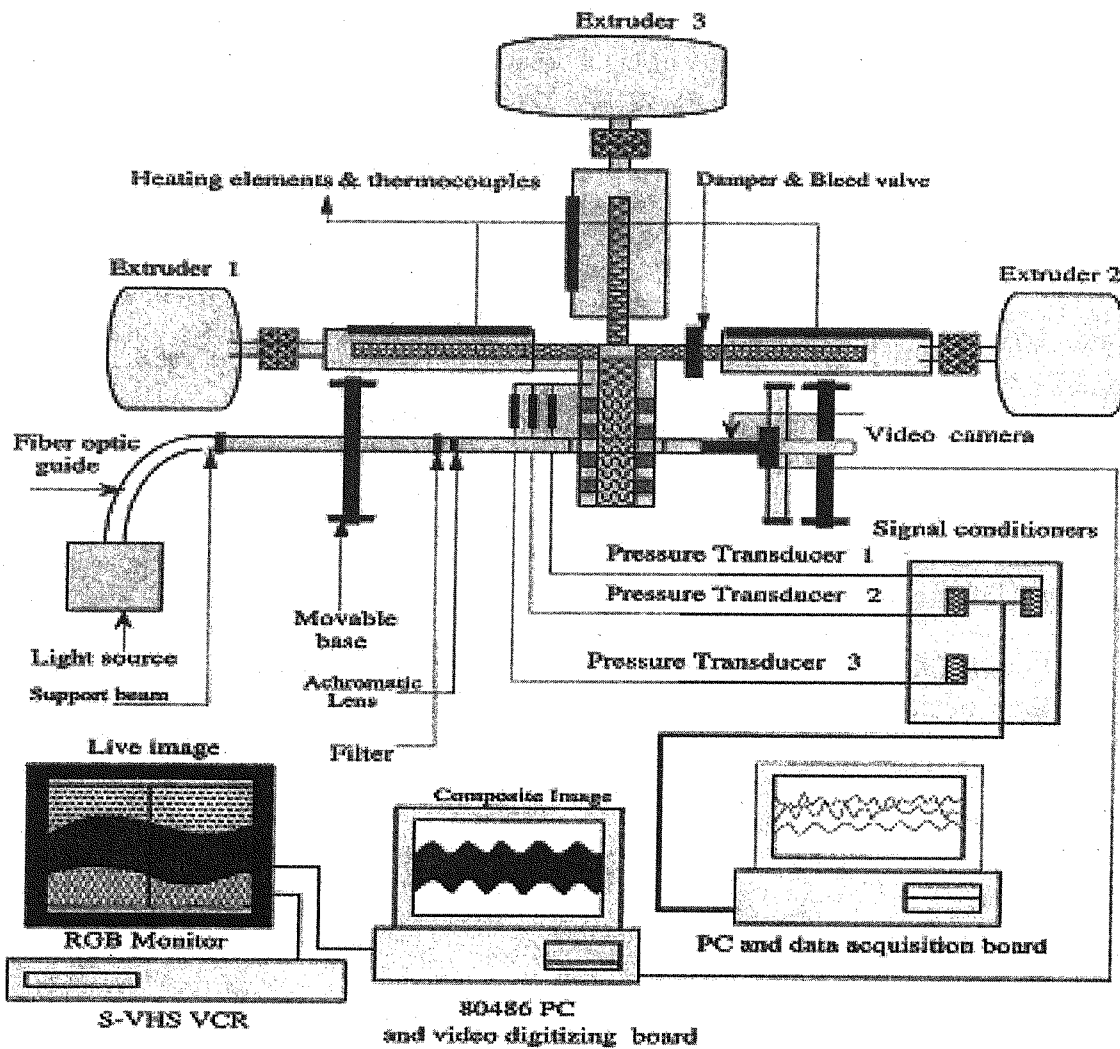


Figure (1).

## Apparatus

The apparatus that was used in our interfacial stability experiments consisted of four main components:

- \*Three laboratory extruders
- \*The test dies including associated fittings, adapters and optical windows
- \*An optical-video train including camera and digital image processing equipment
- \*Pressure input measurement equipment

The experimental set-up is shown schematically in Figure 1. All extruders are 3/4",25:1. All extruders utilize a single flight, constant taper screw with extruder #1 having a 2:1 compression ratio, extruder #2 having a 4:1 and # 3 having 3:1 compression ratio. The optical

that shear thinning of viscosity greatly affects the stability of the interface, and these effects are more pronounced when shear thinning is more significant in the less viscous layer. In the study of interfacial instability, the most dangerous mode is not necessarily associated with long waves, so one needs to study the stability of the interface to all disturbance wavelength. It has been shown [3-4] that the elasticity and viscosity ratio as well as interfacial forces play a crucial role in determining the stability of the interface at all disturbance wavelengths. Recent studies [2-4] have shown that even in the absence of any viscosity and density mismatch, elasticity stratification is sufficient to cause interfacial instability at small or vanishing Reynolds number. In addition they have shown that dominant wave number is of order of unity when non-dimensionalized with respect to the thickness of the more viscous or elastic fluid. These studies indicate that when the less elastic fluid is the majority component (i.e., occupies more than half of the channel) the jump in the normal stress across the disturbed interface is destabilizing, otherwise it is stabilizing. These regions can be used as operating windows for coextrusion process.

### **Experimental Investigations in Interfacial Instability**

Previous experimental investigations in interfacial instability are limited to two different studies. The experimental study of two-layer co-current flow consisting of oil and water in a rectangular channel. The primary result of this study has shown the stability as a function of wave number and the water layer Reynolds number. Since, the experiments were performed at high Reynolds number no information regarding the stability of the interface was obtained. The second investigation reported was dealt with the interface stability of a two-layer coextrusion flow. The approach was to determine the position of the interface and the nature of the shear field through numerical simulation using the truncated power-law model coincident with experimental trails to determine when instability was present. The results have shown stability as a function of interfacial viscosity ratio and depth ratio and first normal stress difference ratio at the interface. Although the study was a good attempt to experimentally characterize the interfacial instability phenomena in multilayer polymeric flows, but the results must be viewed with skepticism since the method for determining the interfacial stresses of two viscoelastic fluids was based on numerical predictions using a constitutive equation that only accounted for the non-Newtonian viscosity of the respective fluids. As with most of the earlier studies the experimental approach did not allow for control of the input disturbances but relied on the full spectrum of disturbances present in the coextrusion process. As a result, the effect of disturbance frequency on the stability of the interface was not considered. In this study a new technique for introducing a known wave was developed.

### **Objective and Scope**

There is a great potential for structural applications of multilayer co-extrusion products. In the manufacture of these multilayer viscoelastic material (i.e., film, sheet, fiber, etc.) existence of interfacial waves are detrimental to mechanical and optical properties of the final product. In the past several years remarkable progress in theoretical and experimental investigations of three-layer viscoelastic fluid have been made [3, 4, 5].

Therefore, continued detailed fundamental studies are required to investigate the effect of multiple interfaces and their potential interactions on the stability and deformation of multilayer viscoelastic flows. The current experimental study was initiated to develop an understanding of the interfacial instability with respect to the role of the various parameter

# Experimental Study of Instabilities in Multilayer Flow of Polymer Melts

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## Abstract

*In the past 10-15 years the need for the development of specifically engineered structures of polymers has resulted in the proliferation of products manufactured using various coating and multilayer extrusion technologies. Utilizing these technologies, great advantages can be achieved by combining polymers of widely dissimilar solid-state structures and properties into unique multilayer blends and composites. However, the manufacture of these products is not without problems. Many processes are currently hindered due to the occurrence of irregular interfaces and undesirable layer distribution. These irregularities are due to the different rheological properties of the material used and can significantly deteriorate the mechanical or optical properties of the product. Hence, to establish guidelines for the overall processing of multilayer coating and extrusion processes, a better understanding of interfacial instability and deformation of multilayer flow of polymeric fluid is required. In this research, an experimental apparatus has been developed for observing interfacial stability and deformation of multilayer pressure driven channel flows. This apparatus has been used to directly observe the deformation of the interface and growth of interfacial waves in order to enhance our understanding of the effect of viscoelastic forces on stability and deformation of multilayer viscoelastic flow. Due to synergetic effects of combining individual polymers, multilayer films and conjugated fibers have been progressively gaining interest in the past decade. In the manufacture of multilayer products, it is a well-known fact that the multilayer extrusion process is more economical than the conventional laminating process. These products are generally superior to their single component counterparts because of the combining materials with different properties into a single structure. This effect is readily observed in the food packing industry where packing films contain multiple layers, each of which contribute a specific barrier, mechanical or optical property to the resultant film. Interfacial instabilities that manifest themselves in form of traveling waves at the interface are the limiting factor in production of multilayer plastic structures. These interfacial waves result in a significant deterioration of the final product's properties of interest (i.e. barrier, mechanical, optical, etc.), hence to better design and control these processes a comprehensive understanding of the interfacial instability phenomenon is required. This would facilitate the selection of materials with suitable rheological properties, proper design of co extrusion die and proper selection of layer ratio within the structure.*

## Keywords

*Multilayer flow, Interface, Instability, Co-extrusion, Wave number*

## Plane Poiseuille Flow

The problem of interfacial stability in plane Poiseuille flow was first addressed [1] using the long wave asymptotic method. The affect of shear thinning viscosity was first investigated[2] using the method of long-wave asymptotics. In this study it was demonstrated