Stagnation Flow Studies of Polymer Solutions in 2D System

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Abstract:
Stagnation flow studies form a key research area in numerous applications dealt with industry. When a fluid approaches a solid boundary, it undergoes severe deceleration along the axis of impingement. We present the experimental findings of the effects of stagnation point on polymeric flow systems. While coating metal sheets or wires with a polymer melt, the metal sheet forms a moving plane on which a steady flow of the melt is maintained. Further in the process the polymer melt cools down and forms a coating. Stagnation region exists around the point where the polymer melt first touches the metal sheet. We try to simulate this situation except in our experiments the solid plane is not moving. The polymer solution flows down the inverted T-channel and strikes the base where we obtain the stagnation region. Laser Doppler technique is used to analyze the flow profile in this region. Initial analysis includes the analysis of a Newtonian fluid which is compared to theoretical predictions. Polyisobutadiene solution with three different concentrations, 0.1%, 1% and 3%, was tested for observing the effect of the change in concentration on the flow patterns around the stagnation point. In the stagnation region the fluid is not completely stagnant but follows a non-streamwise motion.

Zusammenfassung:
Analysen von Staupunktströmungen stellen ein Hauptuntersuchungsfeld in zahlreichen industriellen Anwendungen dar. Wenn sich eine Flüssigkeit einer festen Berandung nähert, erfährt sie eine starke Abbremsung entlang der Achse des Zusammenstosses. Wir zeigen die experimentellen Befunde des Einflusses des Staupunktes auf Polymerströmungen. Während der Beschichtung von Metallflächen oder Drähten mit einer Polymerschmelze bildet die Metallfläche eine bewegte Ebene auf der die stationäre Polymerströmung aufrecht erhalten wird. Später im Prozess kühlt die Polymerschmelze ab und bildet eine Beschichtung. Eine Stauzone besteht um den Punkt, an dem die Polymerschmelze die Metallfläche zuerst berührt. Wir versuchen diese Situation zu simulieren, mit der Ausnahme einer nicht bewegten festen Ebene in unseren Versuchen. Die Polymerlösung fliesst durch einen auf dem Kopf stehenden T-förmigen Kanal und trifft auf die Grundfläche, wo wir eine Stauzone erhalten. Eine Laser Doppler Technik wird benutzt, um das Geschwindigkeitsprofil in dieser Zone zu analysieren. Die Anfangsuntersuchungen beinhalten die Analyse einer Newtonschen Flüssigkeit welche mit mit theoretischen Vorhersagen verglichen werden. Polyisobutadienlösungen mit drei verschiedenen Konzentrationen von 0.1%, 1% und 3% wurden getestet, um den Einfluss der Konzentration auf das Flussverhalten in der Stauzone zu untersuchen. In der Stauzone wird das Fluid nicht vollständig aufgestaut sondern folgt einer nicht-stromartigen Bewegung.

Résumé:
Les études de stagnation dans l'écoulement forment un domaine fondamental de recherches dans de nombreuses applications relevantes pour l'industrie. Lorsque un fluide approche une surface solide, il subit une grande décélération suivant l'axe d'incidence. Nous présentons des résultats expérimentaux sur les effets du point de stagnation dans l'écoulement de systèmes polymériques. Lors du revêtement de plaques métalliques ou de câbles métalliques avec un fondu de polymère, la plaque métallique forme un plan mobile sur lequel un écoulement continu du fondu est maintenu. Par la suite, le fondu de polymère refroidit et forme un revêtement. Une région de stagnation existe autour du point où le fondu de polymère touche en premier la plaque métallique. Nous avons tenté de simuler cette situation, sauf que dans nos expériences, la surface solide ne bouge pas. La solution de polymère s'écoule le long d'un canal en forme de T inversé, et heurte la base où nous obtenons une région de stagnation. La technique de Laser Doppler est utilisée pour analyser le profile d'écoulement dans cette région. Une analyse initiale inclue l'étude d'un fluide Newtonien qui est comparé aux prédictions théoriques. Des solutions de polybutadiène avec trois concentrations différentes, 0.1%, 1% et 3%, ont été testées afin d'observer l'effet de la concentration sur les changements de la figure d'écoulement autour du point de stagnation. Dans la région de stagnation, le fluide n'est pas tout à fait stagnant mais suit un mouvement contre-courant.

Key words: stagnation flow, Laser Doppler Velocimetry, 2D flows

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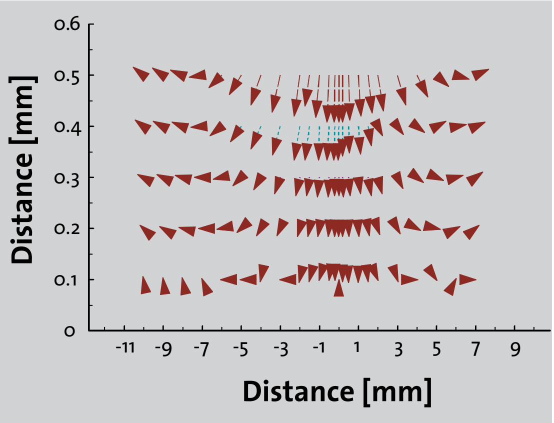

Figure 10: Magnified view of the vector plot in the 'Stagnation Zone' with y - axis as the gap marked in mm for 0.1% polymer solution.

cates no reversals in the flow direction which is a point of concern for the coatings industry.

The data obtained here leads to the conclusions that there definitely exists a non-streamwise motion of the fluid in the stagnation zone. Increase in concentration indicates an augmented effect on the behavior of the flow profile in the zone. As noted, the 1% solution compared to 0.1 % solution the stagnation zone has fluid moving with lower velocities in spite of greater mainstream velocity.

Further increasing the concentration to 3 % polymer changed the trend. The mainstream velocity upstream was adjusted to 0.15 m/s, which is the highest among all the test solutions used. But here the trend of lowering the stagnation region velocities does not continue as can be observed in Fig. 9. The velocities in the stagnation region are greater than that for the 1 % polymer solution. This observation adds an interesting point to our results. The stagnation region does not seem to head towards a complete stagnation simply by increasing the polymer concentration.

These observations are still insufficient to predict the behavior of highly concentrated solutions or polymer melts in this type of a flow. A possibility of flow reversals or formation of eddies cannot be eliminated for higher concentrations. An added energy due to increased mainstream flow velocities but enhanced polymer interaction due to increase in concentration could produce small re-circulations in stagnation region. Our observations indicate the flow to be remarkably sensitive to increase in concentration. This observation brings in a lot of optimism for expecting drastic changes in flow profiles inside the stagnation zone for exceptionally high concentrated polymer solutions or melts.

CONCLUSIONS

Results have been compared with previous experiments and have been proved to show good agreements. As far as experimental findings are concerned, the constructed apparatus works well with the parameters chosen and successful data acquisition is done close to the walls. The refractive index matching technique has been mastered for the measurements to be done in close proximity of the wall. LDV technique is an accurate non-evasive technique, which provides good spatial resolution to study the kinematics of stagnation region. The experimental Newtonian velocity profiles indicate excellent agreements with theoretical calculations. This comparison provides us with a good idea on the authenticity of the data acquired by the LDV technique.

Increase in the concentration of polymer has shown to affect the stagnation zone significantly. The thickness of the stagnation zone has also been shown to increase with increase in concentration to a certain limit. The S-shaped profiles deviate significantly from Newtonian flow profile at higher concentration of the polymer in the solution. This indicates increased polymer interaction around the 'Stagnation Zone' with increased Deborah number. No definite conclusions can be drawn about how the polymer would behave at higher concentrations. The data acquired in the range of concentrations tested shows significant change. A clear non-streamwise motion is observed in the stagnation zone. Whether or not the flow would become completely stagnant in the region of stagnation zone is not clear for increased polymer concentrations.

To extend this work further, simulations could be done using ALSC model and compared to the experimental findings. If proved to agree, then effects of varying different parameters like aspect ratio of flow channel or increased polymer concentration could be determined apriori and then confirmed using experiments. Further investigations could be done to obtain a better solvent to increase polymer concentrations. By using polymers with different molecular structure, the effects of molecular structure on the behavior of 'Stagnation Zone' could be explored. Since the change in concentration of the same polymer introduces significant changes in flow behavior, it is certain that different kind of polymers would show varied behavior in this flow, as the kind of molecular interactions in the stagnation region would change.

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