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Novel Turbulence Absorption Technique for Enhancing the Liquids Flow in Pipelines

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Abstract **-** In the present work, an new technique for enhancing the flow in pipelines is introduced. Such technique depends on inserting Turbulence Absorbing Unit, TAU with certain dimensions inside the pipe. This unit was designed to absorb and redirect the turbulent structures inside the pipelines. Liquid circulation system with a testing section divided into four subsections was fabricated and used to test the drag reduction effect of the new technique. The results showed that almost 30% flow enhancement is achievable when inserting 12 strips with 20cm length into 0.0381 m diameter pipe.

Keywords**:** Drag reduction, Turbulent flow, Mechanical device, Pumping power losses.

1. Introduction

Transporting fluids through pipes is known to be an energy intensive process due to the turbulent mode these fluids are transported in. As such, the science of reducing this turbulence or drag reduction is a field of great importance from both economic and academic perspectives. Since the early discover by Toms (1949), polymeric additives have been known to significantly reduce drag even when used in minute quantities. Along with surfactants and suspended solids, polymers are part of a group of additives that have established a foothold in virtually all industries which require flow enhancement. A few parts per million of these additives can produce drag reductions ranging from 20 to 80% (Gyr and Bewersdorff, 1995)

Despite the remarkable success of these additives in reducing drag, they are not without faults. Additives necessarily alter the physical and sometimes chemical make-up of the fluid they are introduced into. While this is acceptable in the vast majority of industries involving fluid flow there are some industries that are intolerant to such alterations. Most commercially used additives are also toxic to both humans and the environment. This makes these additives unfeasible on the long term from an environmental and health standpoint and their application is therefore somewhat limited. Industries in which the end product is meant for human consumption such as the pharmaceutical or food and beverage industry cannot use such additives to improve flow. To top it off, these additives degrade in the turbulent flow as they progress downstream. Long chained polymers are especially vulnerable to scission due to high shear stress which causes the chains to gradually become shorter to a point where they are ineffective as drag reducing agents. At this point more additives must be reintroduced to maintain the same flow throughput. The effects of these additives are therefore transient in nature, highlighting the need for a more permanent solution to the problem of pumping power dissipation. In search of such a solution, many researchers have turned to non-additive methods of drag reduction. The most popular of these methods are riblets, oscillating walls, compliant surfaces and microbubbles.

Riblets are essentially longitudinal microgrooves etched onto the wall surface which reduce drag and increase the surface area available for heat and momentum transfer. It is popularly accepted that riblets reduce drag by limiting the meanderings of quasi-spanwise vertical structures (Choi, 1989: El-Samni et al., 2007) and by viscous interaction within the riblet valleys (Djenidi, 1994; Park and Wallace, 1993; Wallace and Balint, 1987). A vast body of research indicates that riblets are capable of drag reduction in the order of 7-10% (Bandyopadhyay, 1986; Baron and Quadrio, 1993; Bechert and Hage, 2006; Choi, 1989; Choi et al., 1993; Chu and Karniadakis, 1993). However, further modifications to the basic riblet design spanning over 15 years seem unable to surpass the 10% DR barrier. For now, it seems that riblets are as optimized as they will ever be. Despite this, riblets already see widespread commercial application in water vessels, heating and cooling devices and even in swimsuits.

Oscillating walls are another interesting non-additive method of drag reduction. These devices are usually built into ducts or rectangular conduits. In most cases the oscillations are spanwise and are driven by motors or actuators. It is widely accepted that oscillations of a suitable frequency and amplitude can curb turbulent activity (Baron and Quadrio, 1996; Jung et al., 1992; Nikitin, 2000). The mechanism by which DR is achieved with oscillating walls is complex but the basic idea involves altering the near wall boundary layer just above the oscillating wall in such a way that homogeneity is achieved and turbulence becomes suppressed. DR as high as 40% has been recorded (Jung et al., 1992) with energetic savings in the order of 10% after deducting the energy spent to oscillate the walls (Baron and Quadrio, 1996). Although this innovation has DR comparable to riblets, it is not as popular due to the cost of installing and maintaining such a sophisticated array of moving mechanical parts. Currently, oscillating walls remain at the laboratory testing stage and is currently unsuitable for industrial use.

Like riblets, compliant surfaces are regarded as a passive means of drag reduction. Compliant surfaces were first popularized by Kramer (1960) with his dolphin skin elastic wall which sported 60% DR – an incredible feat at that time. Unfortunalety, other researchers using Kramer-like surfaces for towing tank experiments in lakes and water channels were unable to produce the same results. This meant that Kramer’s compliant surface lacked versatility and could only be used under very closely controlled experimental conditions – thus making it impractical for commercial use. In a more recent study, Cai et al. (2008) used a flexible tube made of silica gel cushioned by a layer of air inside a pipe. The drag reduction achieved was a modest 12% which is closely comparable to other non-additive means of DR discussed previously. Similar to the oscillating wall however, this method is currently unpopular due to the complex experimental set up considering that the results are only marginally better than riblets.

Microbubbles are only loosely considered a non-additive method of drag reduction in that a new substance not native to the fluid is in fact being introduced into it. However, the bubbles are generally produced from water through electrolysis or are taken from the surrounding air thus eliminating the need to actually acquire the additive. This method was first introduced by McCormick and Bhattacharyya in 1973 with the intent of reducing drag on ship hulls. The bubbles in question were in fact hydrogen produced by electrolysis of water which resulted in up to 65% DR. As the name insinuates, microbubbles are very small bubbles with diameter in the vicinity of 0.1mm or less which are produced by forcing the gas through a series of porous filters. Above this threshold diameter value, the bubbles have no drag reducing effect on the flow. While this method is somewhat popular for use on ships it is not a practical method for drag reduction in pipes simply because the bubbles coalesce further downstream and increase in size to a point where they are no longer useful drag reducing agents. Until a remedy can be found to prevent or slow the coalescing process of the bubbles, this method remains unsuitable for pipeline flow enhancement.

The non-additive methods of drag reduction discussed all fall woefully short compared to additives in terms of performance especially for application in pipeline fluid transport. However, it is a display of evolution at work as researchers seek a more permanent and intrinsic solution to the pumping power loss problem as opposed to the temporary fix provided by additives. Ironically, it is this same evolution that inspired the present technique. For centuries man have studied the natural world and attempted to simulate the many aspects of it to solve various engineering problems; flight, energy conservation and drag reduction are among the problems that other living creatures have evolved to develop special means of handling. Biomimicry has seen particularly abundant application in the field of drag reduction. For example riblets aim to simulate shark skin, compliant surfaces take after dolphin skin and the streamlined shape of submarines closely mirror that of most aquatic life.

The present technique of drag reduction using flexible pseudo inner surfaces is an adaptation of the method used by cephalopods such as squid and octopi. These creatures use a jetting system to propel them forward in bursts. For squid in particular, water enters the inlet mantle and is expelled suddenly by a contraction of its body. The point of interest here is the difference between the projected acceleration and that actually achieved. It was found that the squid's acceleration exceeded predictions by 20-30% (Stewart, 2010). The only plausible explanation for this is the effect of the squid's tentacles in reducing drag and vortex shedding after the expulsion of fluid. This was later confirmed using digital imagery which revealed subtle wake patterns following a squid's speed burst. Drawing on these findings, the present study employs a pseudo inner surface attached at one point onto the pipe wall comprising 12 strips of rubber. This setup is expected to alter the wall boundary layer dynamics as well as the way vortical structures form and propagate in the turbulent flow.

2. Material and Methods

2.1 Experimental Set-up

The experimental set-up is shown in Figure 1. The rig essentially comprises a reservoir, a centrifugal pump, a flow meter, a series of five pressure transmitters (PT-101 to PT-105) and a removable pipe section connected with flanges in order to insert the device being tested. The pipes are made of galvanized steel in order to simulate industrial standards with an internal diameter of 1.5 inches throughout the system. Only the removable pipe section is made of clear plastic with PVC fittings. The system is designed to circulate liquid in a closed loop and is driven by a Grundfos CH8-40 centrifugal pump which delivers 1kW of pumping power. The flow rate is measured by a Burkert attachable flow meter which has a sensitivity of up to 0.01 cubic metres per hour. The point pressure is detected by the five Baumer differential pressure gauges (PT-101 to PT-105) which are separated by half metre intervals. The valves are used to control the flowrate and the data collected by the pressure transmitters is processed by a SCADA (supervisory control and data acquisition) system which is used to monitor and store data. For the purposes of the present study, the fluid used is water. The pump draws the water from the reservoir tank and drives it through the flow meter, control valve, removable pipe section (where the TAU will be inserted when the experiment is being carried out) , past the five pressure transmitters and back into the tank. The bypass and drain pipes are used for cleaning and maintenance purposes.

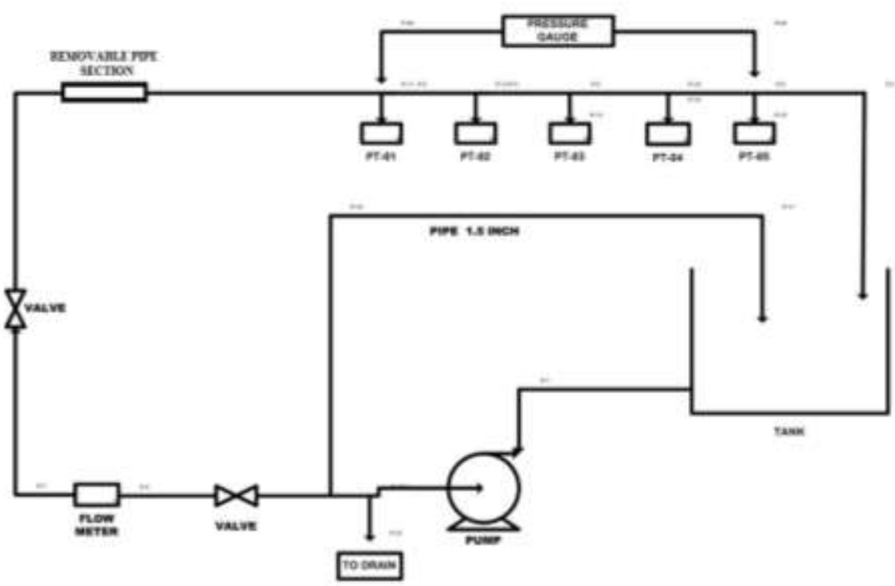

Fig. 1. Closed-Loop Circulation Rig.

2.2 Turbulence Absorbing Unit, TAU

The device is made of an aluminium ring with 12 strips of rubber attached to it as shown in Figure 2. The aluminium ring has a diameter such that it fits snugly into the removable pipe section (outer diameter of approximately 1.5 inches). The rubber strips were cut from sheets of neoprene rubber (widely used for electrical insulation in power stations) and were 2.5 millimetres thick, 5 millimetres wide and of equal lengths. Neoprene rubber was selected as a suitable material due to its elasticity, toughness and moisture resistance. The length of the strips is one of the independent variables and the lengths tested ranged from 10 centimetres to 30 centimetres. One end of each strip is attached to the ring using glue. Before attaching the end is first sliced with a blade such as to produce a gentle tapered slope of approximately 30 degrees to the normal. The tapered end is then rubbed against a rough surface to smoothen it out and remove deformities in the rubber. The purpose of this is to reduce the turbulent wake that would be created from a high speed flow colliding with a rectangular block of rubber in the pipe; a gentle slope would induce a slower onset of turbulence instead. The close-up in Figure 3 gives a clearer view of the tapered ends.

Fig. 2. Front view of Turbulence Absorbing Unit.

Fig. 3. Close-up on front view of TAU.

The ring with its 12 strips of neoprene rubber is used as a Turbulence Absorbing Unit (TAU) and was attached to the removable section of the pipe with the aid of a little silicone sealant when the occasion called for it. Like its name suggests, the TAU acts as an alternative inner wall which oscillates naturally with the turbulent flow in such a way as to reduce the production and propagation of turbulent eddies and vortexes. The hypothetical mechanics of the device is explained more elaborately later on.

2.3 Research Procedure

A control run using water as the fluid medium and no device was first carried out. The flowrate was controlled such that pressure data was collected for the range flowrates from $5m^3/h$ to $9.5m^3/h$ with $0.5m^3/h$ intervals. In this experiment it was of extreme importance that the temperature be controlled since this has a great influence on the degree of turbulence and represented a very potent confounding variable. The immense Reynold's shear stress produced by the pump meant that the water would gradually heat up the longer the pump was left on. To minimize this effect, the reservoir was emptied out and refilled again each time data for two flowrates were recorded. This procedure was practised throughout the remainder of the experiment. A valve is adjusted to get the desired flowrate and after each adjustment there is a two minute period where the flowrate fluctuates wildly while the system attempts to reach a steady state. This is expected as the valve used to control the flow is located after the flow meter which meant that any adjustments to the valve would be subject to a delayed response from the flowmeter. However, this valve was used because the delay and fluctuations are indications that the system has not achieved a steady flowrate and once a steady flowrate can be read the reliability and accuracy of the reading is improved. As such, all readings are taken after two minutes have elapsed from the moment the valve is moved from its previous position. The full control run is performed three times in total and the average taken to further improve the accuracy of the findings.

Upon completion of the control run, the removable pipe section is disconnected and the device placed into the pipe. The TAU is tested for a range of lengths from 20cm to 130cm. The TAU with the longest strips are used first and the rubber is truncated by 10cm prior to each consecutive run. This is done to ensure that the differences between the tapered ends do not affect the experiment. For the longer TAU it proved to be a challenge to insert the entire length of rubber into the pipe without jamming the pipe or the rubber folding on itself. To avoid these problems, a long metal ruler was used to coax the rubber in. For each length of TAU, the experimental procedures used for the control run were replicated.

3. Result and Discussion

Figure 4, show an example from the experimental work conducted. This figure shows pressure drop influenced by the mechanical device of 10cm, 15cm and 20cm length on 0.5m pipe at Re = 95250.00. It is clear that the pressure drop readings with time for the devise-free flow system is higher than those recorded with the TAU installed in the pipe. Also it can be clearly seen that the isolation of the pressure drop readings were lower and the readings appears smoother. This figure shows that the best pressure drop results (lower pressure drops) was achieved by using TAU with 20 cm length, and that should give a clear indication regarding the direct relation between the strip length and the drag reduction efficiency. This is not expected to be unlimited, where the longer the strip length, the heavier the strip itself and that can act as an altering factor as will be shown later.

The 15cm mechanical device is efficient at pipe length 1.5m with the highest drag reduction of 27.8% at Reynolds number 58208.33 (refer Figure 6). Whereas 18.23% drag reduction obtained for 20cm mechanical device for the same Reynolds number. In Figure 5, 18.23% drag reduction resulted for 20cm mechanical device for Reynolds number 58208.33 on 2m pipe. For 0.5m pipe, 25.42% drag reduction is achieved for 20cm mechanical device for Reynolds number 95250 (refer Figure 7). While 15cm mechanical device contributes 24.57% of drag reduction on the same Reynolds number. The application of mechanical device caused significance reduction in the degree of turbulence. Similar trend of graph was achieved for the comparison of tested different pipe length. There is a pulse of drag reduction in the initial flow rate of the water and steadily reduces the fluctuation of the pressure drop in the water flow. This action was repeatable where almost the same behavior was observed when the experiment was repeated from four times. It is believed that this pulse is a clear indication of the balancing behavior between the strips and the degree of turbulence where it can reach its drag reduction optimum performance at this point with the specific design features. This is expected not to have the same effect at different Reynolds number because when the flow rate is changed, the degree of turbulence will change also and that needs other strips dimensions to be able to work.

Figure 8 shows the suggested and expected mechanism controlling the drag reduction performance of the new technique. It is expected that the strips will act as a thick "look-like" laminar sub-layer that have the needed flexibility to absorb the turbulent structures (eddies) that approach the pipe surface and that will lead to either absorbing these structures due to its interference with the eddies themselves, or it will re-direct these structures towards the center of the pipe which will create dense turbulence core in the middle of the pipe that is directed towards the flow direction. The strip oscillation is an interactive relation between the degree of turbulence, liquid type, strip material type and strip dimensions. It is hard at this stage to determine specifically the direct relation between all these factors due to the very complicated and interactive behavior but it was observed that it is a one-point relation where all these factors works in the same time to achieve the desired target (drag reduction).

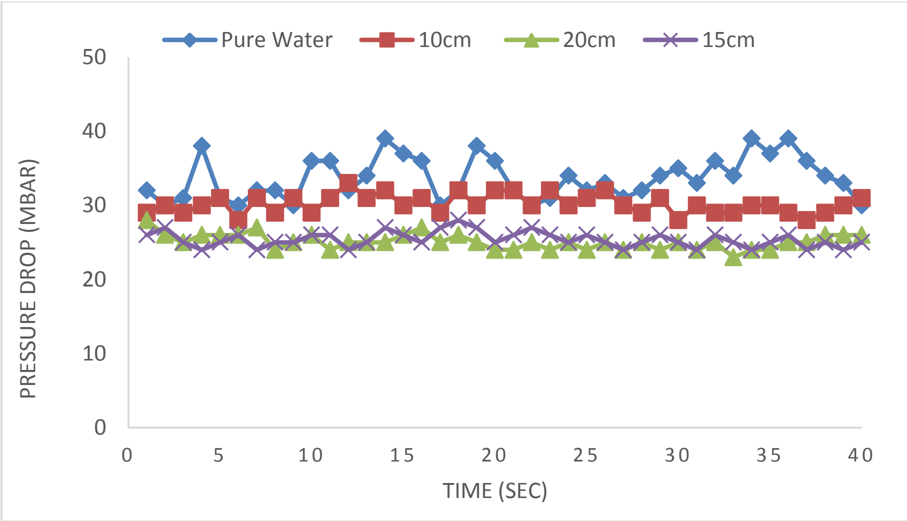

Fig. 4. Pressure drop influenced by the mechanical device of 10cm, 15cm and 20cm length on 0.5m pipe at Re = 95250.00.

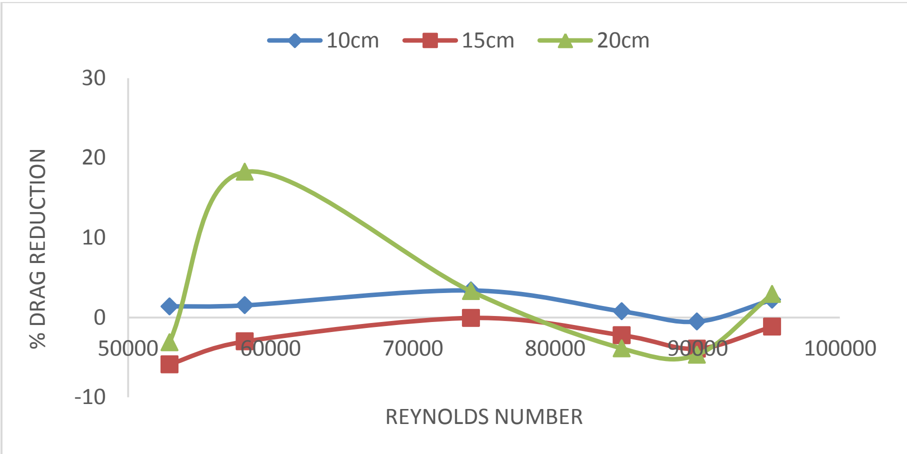

Fig. 5. Relationship between percentage of drag reduction and Reynolds number and with different length of mechanical device of 10cm, 15cm and 20cm on 2m pipe.

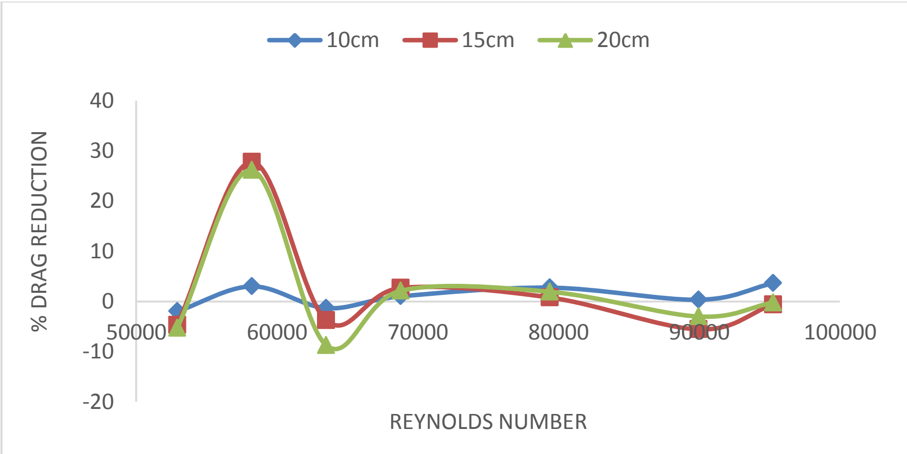

Fig. 6. Relationship between percentage of drag reduction and Reynolds number and with different length of mechanical device of 10cm, 15cm and 20cm on 1.5m pipe.

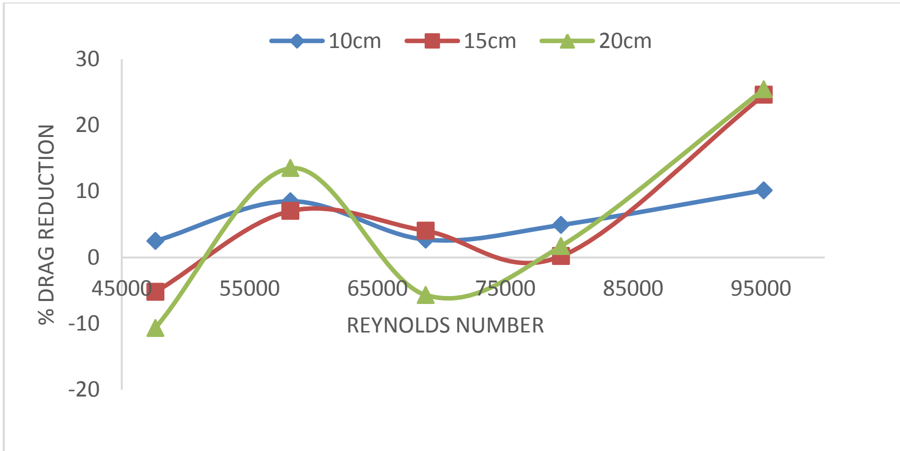

Fig. 7. Relationship between percentage of drag reduction and Reynolds number and with different length of mechanical device of 10cm, 15cm and 20cm on 0.5m pipe.

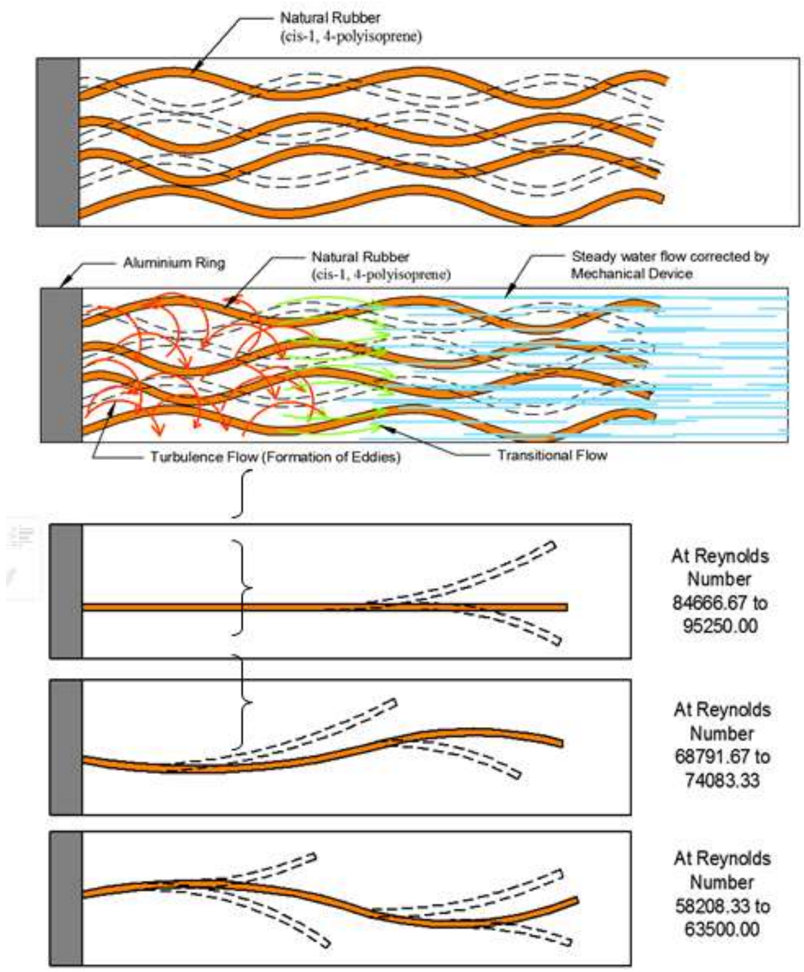

Fig. 8. The mechanism of water flow in pipeline with the presence of mechanical device.

4. Conclusion

The new mechanical technique for drag reduction using Turbulence Absorbing Unit (TAU) was successfully tested with reduction in drag up to 27.8%. It is believed that the mechanism of drag reduction by the application of mechanical device strongly relates to the redirection of the turbulence flow generated during the pipeline transportation. As the result, eddies formation, which is associated with high momentum fluid in the pipeline is destabilized leading to reduction in turbulent fluctuation by the assist of flexible nature contributed by the invented mechanical device. The turbulent pipeline systems with the fabrication of mechanical device have a convincing result for industrial purpose which deals with major pipeline transportation system.

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