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Experimental Investigation of Hydraulic Capsule Pipeline with Drag Reducing Surfactant

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ABSTRACT
An experimental investigation was carried out to determine the effects of drag-reducing surfactant additives on the performance of hydraulic capsule pipeline . The investigation was carried out using two surfactants; sodium laurel sulphate (SLS) and dodecyle benzene sulphonate (DBS) with concentrations up to 350 ppm to clarify their effects on capsule tilt velocity, capsule velocity and pressure gradient .It was found that the surfactant additives reduce the pressure drop along hydraulic capsule pipeline and capsule tilt velocity, while capsule velocity especially is not affected by surfactant additives concentrations. Appreciable drag reduction was attained when using surfactants of 50 ppm concentrations. Faster speed of freight transportation through capsule pipeline is attained without additional pumping energy by using surfactant additives.

Keywords: Hydraulic capsule pipeline; drag reduction; capsule velocity; capsule tilt velocity; surfactant.

INTRODUCTION

The current highway system is approaching saturation with ever-increasing traffic in both freight transportation and human movement. Many of the nation's roads are clogged and congestion continues to worsen. The conventional approach of building more roads has ceased to be effective for both fiscal and environmental reasons. Research is being conducted to enhance capacities of the existing infrastructure. At the same time, it is important to study new transportation systems [1].

Hydraulic capsule pipelines (HCP) is a freight transportation mode in which hollow capsules (either cylinders or spheres) are filled with cargo or cargo itself is formed into solid capsules. These capsules are transported over long distances from location to another through pipes that use water as the carrier. This method of freight transportation has several advantages, such as:

1- Separation of fluid phase and material transported is not required;
2- Material at the destination is available in a dry state and expenditure on drying of material is involved;
3- Fluid is not contaminated and can be recycled ;
4- Properties of the material transported are maintained;
5- There is no traffic jam, no accidents and no loss of lives and properties as the pipeline is usually underground.
6- Have little environmental impact on surroundings once installed and can work regardless of weather conditions.
7- Lowest cost for freight transport as compared with transportation modes in many situations.
8- Public desire to reduce reliance on trucks and trains due to serious pollution and safety problems, and increased congestion of highways and streets.
9- Free from cargo theft during transportation.
10- Advantage of underground pipelines from a land use standpoint.
11- Increased population and increased demand for freight transportation.
12- Advancement of freight pipeline technology and computer control, making it feasible to use improved and reliable freight pipeline systems hitherto not feasible. Such advancements include better welding technology to prepare steel pipe with smooth joints,

better pipe bending to produce bends of smooth radius and least pipe ovality, better control of corrosion, advanced pigging technology and inspection of pipe interior, trench less technologies (computer guided directional drilling) for construction of underground pipelines to cross roads, rivers, and other obstacles, computer control of pipeline systems and so on.

13- HCP have been found to be more economic than slurry pipelines.

Wide application of HCP for solid transportation over long distances requires the minimization of energy consumption. To increase the capsule velocity and to reduce pressure gradient due to capsules, Ellis et al. [2] recommended that the clearance between the capsule and the pipe bottom should be supported in a slightly nose-up position by using a simple collar around the leading half of the cylindrical capsule. They[3] also investigated several methods to reduce the pressure gradient by modification of the capsule surface which brings about the reduction of the friction coefficient. Fuijiwara and Tomita [4] indicated that the existence of helical ribs on capsule surface is an effective method to increase the velocity of heavy capsules. They indicated that when the capsule velocity is larger than water velocity, the pressure line does not change by capsule passing.

Valsak [5] ,in an experimental study conducted on the hydrodynamics of capsules in anomalous shapes , indicated that the semi-rigid capsule trains have about 20% lower pressure gradient than trains consisting of identical solid capsules for Reynolds number less than 5x 10^5.

Yoshinari et al [6] in an attempt to reduce energy consumption in hydraulic capsule transport by injecting polymer additives of concentration up to 500 ppm solution into water flow from pipe axis near the pipe inlet. They indicated that the pipe friction loss coefficient was reduced to about 1/3 for Reynolds numbers of 10^4 to 6.5x10^5. They found also that the capsule velocity was increased about 50% by additives.

Vlasak[7] indicated that experiments done using two polymers: Percol 140 ,Polyoc coagulant resulted in maximum drag reduction of 35 and 50% respectively, but this effect very quickly decreased or even vanished due to mechanical degradation of macro-molecules in the used installation with centrifugal pump.

Vlasak[7] used water and dilute water solution of SEAN, (mixture of Septonex and I-Naphtol), with weight concentration =0.067 and 0.1%) as a carrier fluid. Drag reduction up to 80% was attained, in the same time its self regeneration ability seems to be very stable and recommended additive for capsule pipeline.

Huang et al [8] indicated that 75% drag reduction in HCP flow is attained when using polyethylene oxide polymer (trade name Polyox, from WSR Coagulant, Union Carbide) solution at concentration of 25 ppm. They noted that rapid degradation of polymer occurred due to the Centrifugal pump or jet pump used to circulate the capsules .Both pumps create large shear stresses that readily break up the polymer chains. They recommended that for large hydro-capsule pipelines, polymers can be injected after each booster pump to prevent polymer degradation and to produce drag reduction over a long distance.

The use of polymers for drag reduction in HCP has been reported. The major restriction on the use of polymer drag reducers is their susceptibility to mechanical degradation which limits their usefulness in pumping systems. Friction loss through piping systems is significantly reduced by use of certain cationic, anionic and non-ionic surfactants. Surfactant drag reducers are also degraded under high shear but quickly regain their drag reduction effectiveness when flowing in region of low shear stress [9-12]. Their long life and greater potential percent reduction in energy loss make them very attractive in HCP with or without recirculation flows.

This paper reports the results obtained from an experimental investigation carried out to determine the effect of introducing different types of surfactants .These include sodium laurel sulphate and dodecyle benzene sulphonate with concentrations up to 350 ppm on hydrodynamics of capsule tilt velocity, capsule velocity and pressure drop. Capsule tilt velocity is determined by minimum bulk velocity required to tilt a stationary capsule, before it starts to slide, against an artificial protrusion. This protrusion may be very small or zero expressing the pipe roughness or finite representing pipe welding

Experimental Apparatus and Procedure

The experimental set-up is shown schematically in Fig.1.The liquid is pumped from 500 lit tank (1) to the piping system using a reciprocating pump (2) driven by 5 kW AC electric motor. The water flow rate through the system was regulated through a by-pass control valve (3) at the pump outlet and flow rate was measured by a calibrated ultrasonic flow meter (4) having average variation of 0.5%. The capsule is fed into the system manually, before pump starting, through ball valve (5) ,then using a long rod to push the capsule until it reaches the stopper (6).The piping system consists of horizontal pipeline loop of 25 mm inner diameter, made of PVC with large radius bends with 3.6 meters made of Plexiglas pipe(test section) (7). Pressure tappings (8) and (9) were used for pressure drop measurements using two u-tube manometers connected in parallel: one contains mercury for high pressure drops while the other contains Carbon Tetra Chloride, is used for measuring low pressure drops. Points (10) and (11) are two marks 1 meter apart on the transparent pipe used for capsule velocity measurements through the test section by Panasonic Digital Video Camera; model number PV-DV402 with digital interface

USB link. The video signal is NTSC color signal. The recording system: 2 rotary heads. Lens filter diameter: 43 mm.

Then the pump is operated and the delivery valve is opened gradually until the capsule is tilted and started to move. The capsule traverses through the test section where the flow rate, pressure drop, and velocity measurements are recorded. After passing through the piping system the capsule is deposited over a wire screen located on the top of the water tank. This allows the use of the capsule several times without interrupting the pump operation.

Cylindrical capsule of 20 mm diameter and 50 mm length made of Aluminum was used in the experimental program..

The uncertainty of the pipe inner diameter is ± 0.2 mm, resulting in an uncertainty of ± 2.5% for the investigated flow ranges.

Experimental program include the effect of using two surfactants: sodium lauryl sulphate (SLS) and dodecyle benzene sulphonate (DBS).

Results and Discussions

The tilt velocity is obtained experimentally for two protrusions (Y) at different surfactant concentrations. Fig.2 for sodium laurel sulphate surfactant and Fig.3 for dodecyle benzene sulphonate surfactant indicated that the tilt velocity increases as the protrusion height (Y) increases. This agrees with mathematical expression for tilt velocity obtained for HCP using water only as carrier fluid pipeline by Cheng et al [13].The Figures also indicate that the tilt velocity decreases as the surfactant concentration increases .This is due to visco-elastic behavior of the solution, which indicates that the wedge effect generated below the capsule surface increases as the surfactant concentration increases and no need for higher bulk velocities for tilting stationary capsules. This effect is very clear for sodium laurel sulphate surfactant.

The pressure gradient, drop per unit length, along the test section is shown for both surfactants in Figures (4-5). It is clear that the pressure gradient increases as the bulk velocity increases in nearly parabolic relation. The pressure gradient and consequently the pressure drop decreases as the concentration of both surfactant increases. The effective reduction in pressure gradient is attained at concentration up to 50 ppm for both surfactants. It can also shown from both figures that for the same pressure gradient along the HCP the bulk velocity increases appreciably as the surfactant concentration increases. For higher concentrations no remarkable drag reduction is observed.

The variation of capsule velocity with both bulk velocity and concentrations of both surfactants is shown in Figures (6-7). Both figures indicated that the capsule velocity is not sensitive to surfactant concentrations at the same bulk velocity.
The figures also indicated that the capsule velocity increases as the bulk velocity increases. This is due to the increase in pressure drop across the capsule itself due to the increase in pressure drop along annular clearance between the moving capsule and pipeline which is approximately proportional to the square of bulk velocity. As the pressure drop across the capsule increases, the driving capsule force increases resulting in increase in final capsule velocity. The combination of Figures (4-7) indicated that for the same pressure gradient along the capsule pipeline as the surfactant concentration increases the bulk velocity increases and consequently the capsule velocity increases. This means that for the same pumping power the freight transportation through capsule pipeline can get faster speed, with great income, without excess running cost to cover additional pumping energy.

Conclusions

1. The used surfactants sodium laurel sulphate and dodecyle benzene sulphonate for concentrations up to 50 ppm show an appreciable drag reduction in hydraulic capsule pipeline .
2. Significant reduction in capsule tilt velocity is attained when using one the used surfactants.
3. Capsule velocity increases as bulk velocity increases in the time it is not affected clearly by surfactant concentrations.
4. Faster speed of freight transportation can be obtained through capsule pipeline without additional pumping energy by using surfactant additives.

Nomenclature

C = surfactant concentration, ppm
D = pipe internal diameter (m)
Δp = pressure gradient (pressure drop per unit length of pipe),Pa/m
R_e = Reynolds number
Q_w =volumetric water flow rate (m^3/s)
V_c = average capsule velocity through pipeline (m/s)
V_t = minimum water flow velocity ,V_w, required to capsule tilt (m/s)
V_w =bulk velocity, water flow velocity through pipeline ($4Q/\pi D^2$) ,m/s

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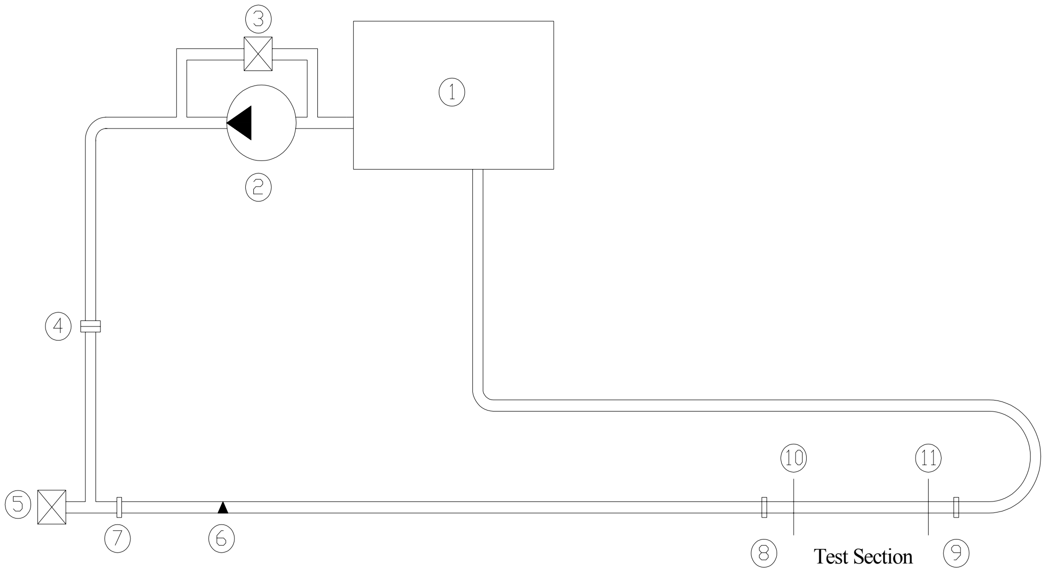

Fig. 1. Experimental Apparatus

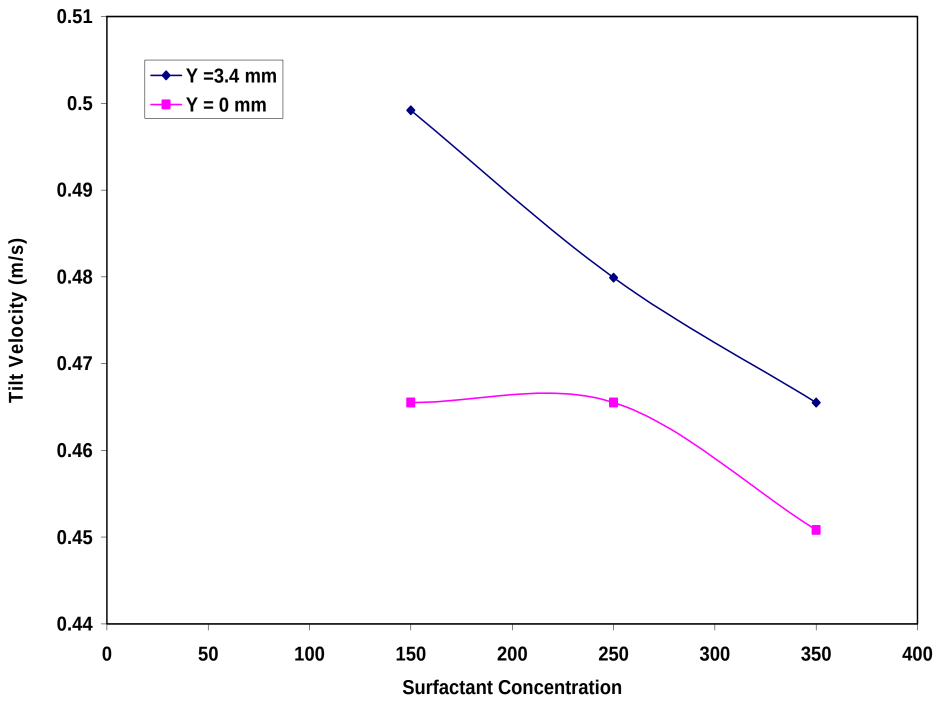

Fig.2 Effect of SLS surfactant concentration on tilt velocity.

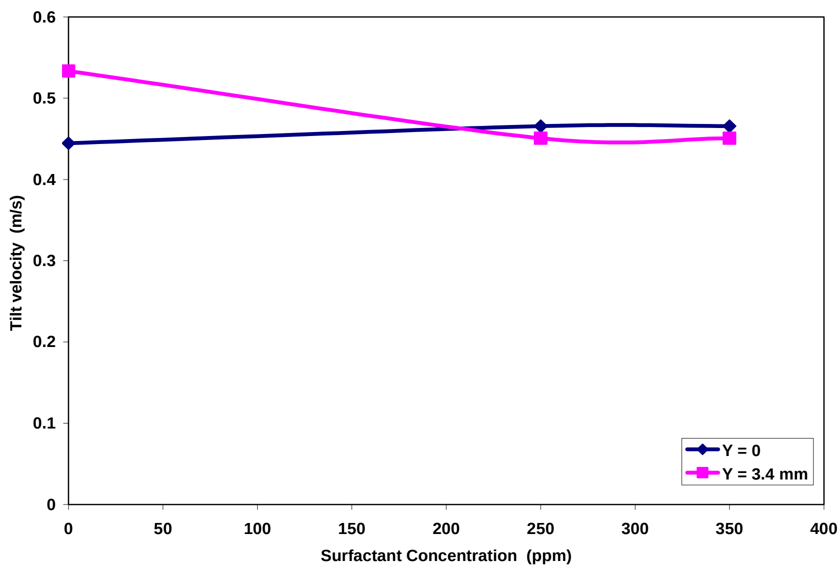

Fig.3 Effect of DBS surfactant concentration on tilt velocity.

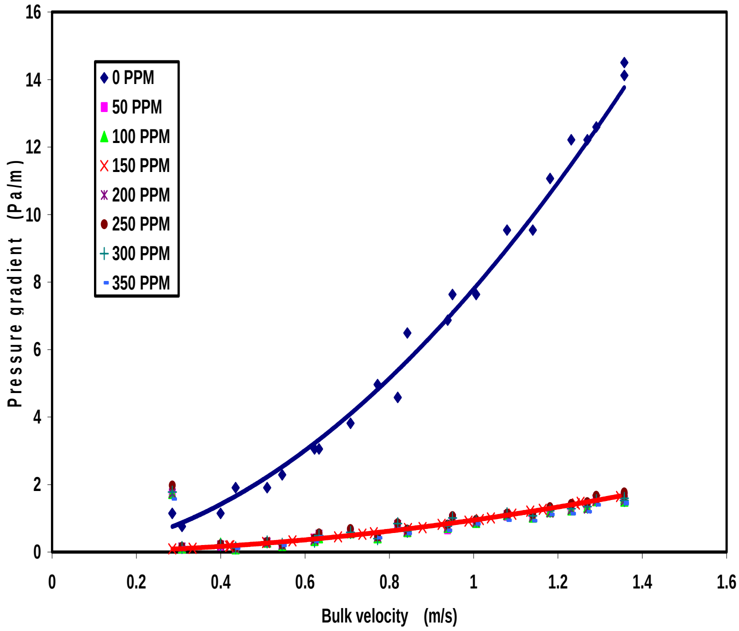

Fig.4 Effect of SLS surfactant concentration on capsule velocity.

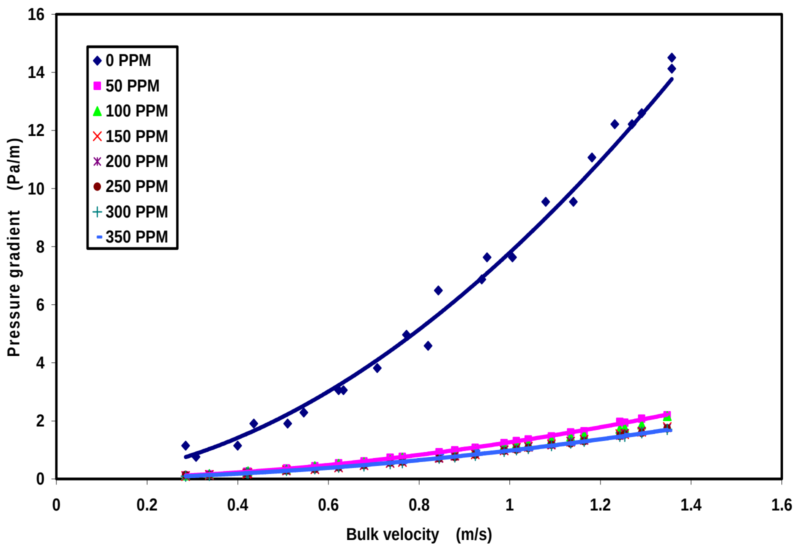

Fig.5 Effect of DBS surfactant concentration on capsule velocity.

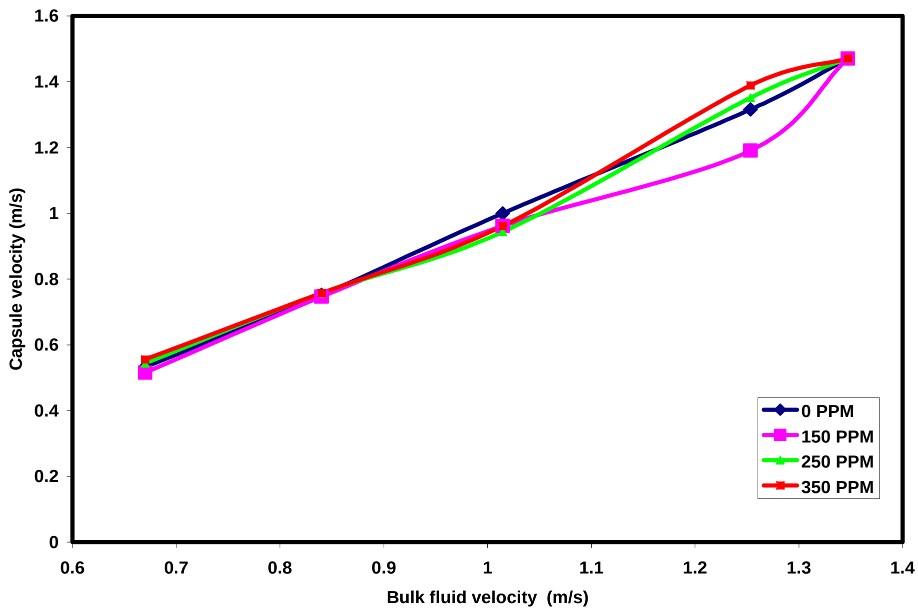

Fig.6 Effect of SLS surfactant concentration on capsule velocity.

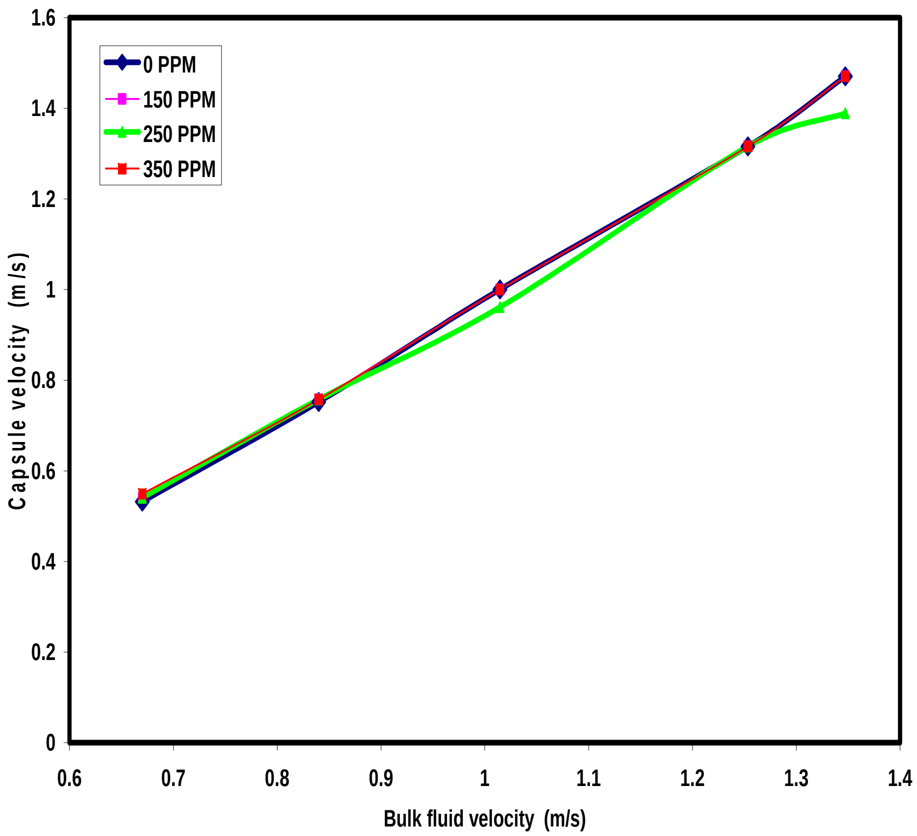

Fig.7 Effect of DBS surfactant concentration on capsule velocity.