Experimental Study For the Transport of Cylindrical Bontaining Sulfur Through a Crude Oil or Water Pipeline

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Abstract

An experimental investigation of the transport of sulfur by plastic flattened cylindrical capsules through the crude oil or water pipeline was carried out in horizontal p.v.c. pipe of 9 m length and 0.046 m bore diameter pipe.

Capsule/pipe diameter ratio of 0.54 and 0.69 were used, aspect ratios varied from 2.2 to 7.2 The average flow velocity varied from 0.37 to 0.43 m/s.

The experimental investigation shows that an increase of diameter ratio increased the pressure gradient ratio. The average flow velocity must be greater or equal 0.37 m/s to ensure transporting in capsule train flow. Capsules of diameter ratio of 0.35 and 0.43 failed in capsule train flow. The minimum pressure gradient ratio can be obtained for capsule length of twice its diameter. The increasing in average flow velocity will increase the pressure gradient ratio for diameter ratio of 0.69, and decreasing the pressure gradient ratio for diameter ratio of 0.54. The use of crude oil as transporting media will give less pressure gradient ratio than water, but it gives more pressure head than water.

Key words : Sulfur , Cylinders , Petroleum and Water

دراسة تجريبية لنقل الأجسام الاسطوانية الحاوية على الكبريت خلال أنبوب النفط الخام أوالماء

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بغداد – العراق

الخلاصة

تم في هذا البحث تعبئة كبسولات بلاستيكية اسطوانية الشكل ذات نهاية مسطحة بمادة الكبريت ونقلها خلال أنبوب النفط الخام، حيث تم نصب منظومة عملية لهذا الغرض والتي هي عبارة عن أنبوب أفقي طوله 9 متر وقطر داخلي 0.046متر مصنع من مادة.P. V. C. لقد تبين لنا بعد الحصول على النتائج لنسب الأقطار قيد الدراسة (0.54، 0.69) للكبسولة وقطر الأنبوب مُوضِحةً نسبة العرض إلى الارتفاع، حيث أنها تتغير من 2.2 إلى 7.2، وبالتالي فأن زيادة نسبة القطر تزيد نسبة تخلخل الضغط، وأن معدل سرعة الجريان يجب أن تكون اكبر أو مساوية إلى 0.37 متر/ثانية لكي تؤمن انتقال كبسولات بشكل سلسلة، وإن الكبسولات ذات نسبة قطر 0.35 و 0.43 تكون فاشلة لتتخذ جريان بشكل سلسلة. من الممكن الحصول على نسبة أدنى ميل ضغط بالنسبة لكبسولة يكون طولها ضعف قطرها، إن الزيادة في معدل سرعة الجريان سوف يزيد نسبة ميل الضغط بالنسبة لنسبة قطر 0.69 و ينقص نسبة ميل الضغط فيما يتعلق بالنسبة قطر 0.54. ان استعمال النفط الخام كوسط ناقل سوف يعطي نسبة ميل الضغط أقل مما هو عليه في حالة الماء، لكنه يعطي ضغط رأسي أكثر مما هو عليه في حالة الماء.

الكلمات المفتاحية: رصاص ، اسطوانة ، مشتقات بترولية و ماء

Introduction

Pipeline science and technology may be regarded as developing through several generations, the first two being fluid and slurry pipeline, respectively. Third generation of pipelines, in which it may be possible to extend the practice and economies of such transportation methods to an even wider spectrum of commodities may be defined as the flow of materials in capsule form as shown in Figure (1); When the fluid used for propelling the capsules in the pipe is air or another gas, it is called pneumatic capsule pipeline. When the fluid for propelling the capsule is water or another liquid, it is called hydraulic capsule pipeline (Hodgson and Charles 1963, Feng and Joseph 1995**,** Round 2009, Gasner 2009).

There are a number of inherent disadvantages associated with the slurry pipeline as means of transportation of solid. These disadvantages are (Thornton 1972):

1- When the solid reacts with or becomes contaminated by the conveying liquid.
2- When separation is expensive.
3- When solids are particularly abrasive.
4- When energy is required to crush the solid to a transportable particle size. Under these conditions the capsule pipelines must be used.

The capsule pipeline is a system which transports solids in capsules carried through a pipeline by a flowing fluid. The capsules may be cylindrical with square or shaped ends and for different lengths and diameters, or they may be spherical shapes. They may be containers of metal or plastic filled with any solid, or they may be formed out of the solid itself as in the case of casting of sulfur or formed shapes of paste such as coal and water. The capsule container may be rigid or, as in the case of plastic container, and somewhat flexible (Govier and Aziz 1972).

Because of the capsule forms occupy appreciably less than the total cross-sectional area of the pipe, they move at a velocity greater than the average over-all velocity. In addition, the pressure gradient of a stream in turbulent flow tends to be reduced, rather than increased, by the presence of capsule forms.

The hydraulic capsule pipeline usually uses water as the carrier fluid and can easily carry heavy materials like ore. The capsule is suspended by water flow without contact with the wall in a horizontal or vertical pipeline even if the capsule is heavier than water. Thus hydraulic capsule pipeline does not always require wheeled capsules. On the other hand, a pneumatic capsule pipeline requires wheeled capsules because air is lighter than water (Tomita 1986).

The capsule pipeline may practical for a wide variety of solids, including wheat and other grains, mineral solids, chemicals, sulfur, manganese and coal.

Advantages claimed for capsule pipeline as distinct from slurry pipeline are (Govier and Aziz 1972):

1- Freedom from contamination and ease of separation of the solid.
2- Lower power requirements per unit of solid transported.

The Disadvantages include :

1- Cost of encapsulating or forming into capsule shape.
2- Mechanical complications associated with the introduction and removal of tthe capsules to and from the pipe at pumping station

There are three types of feasibilities tested to transport the coal by using hydraulic capsule pipeline (Liu 1981):

1- The study found that hydraulic capsule pipeline is technically feasible.
2- It found that hydraulic capsule pipeline is the most environmentally and socially desirable way to transport coal because it reduces the transportation accidents and loss of lives, reduction of noise, air pollution and traffic jams, conservation of energy, and reduced reliance on oil as energy source.
3- It is found that hydraulic capsule pipeline, is always cheaper to transport coal than by truck or even train.

There are many authors study the capsule flow such as:-

Ellis *et al*. (1964) have reported fundamental work on the flow of single spherical and cylindrical capsules in a 1¼ inch plastic pipe. They found that capsules moved at velocities up to 15% greater than the average water velocity.

Jeansen and Bruse (1970) reported pressure gradients for steel and for plastic capsules of identical dimensions and weight, flowing in water a copper pipe. They found that the pressure gradients for the steel capsule were 50% higher than for plastic capsules.

Liu et al. (1981) developed a simple way to pump capsules by using jet pump. They also designed another type of capsule pump, which is a reciprocating type .

Polderman (1982) developed a more accurate calculation method which is based on the velocity profile in annulus between the capsule and the pipe wall.

Marcu (2000) focused on reducing maintenance requirements by designing a new wheel cluster that is theoretically capable of remaining in use for 20 years without stopping.

Liu *et al*.(2001) in their capsule pipeline research center at the University of Missouri, discovered that the use of a small amount (25 ppm) of polyethylene oxide enables drag reduction of as much as 75% in the capsule flow when capsules are at or above the lift-off velocity .

In this work, we should be design and build an suitable system to study the methods of injection, ejection and pumping a train of capsules through a crude oil pipeline. The present study will include the effect of some variables on the pressure gradient caused by cylindrical capsules filled with sulfur such as average flow velocity, aspect ratio (L_c/d) and diameter ratio (k=d/D).

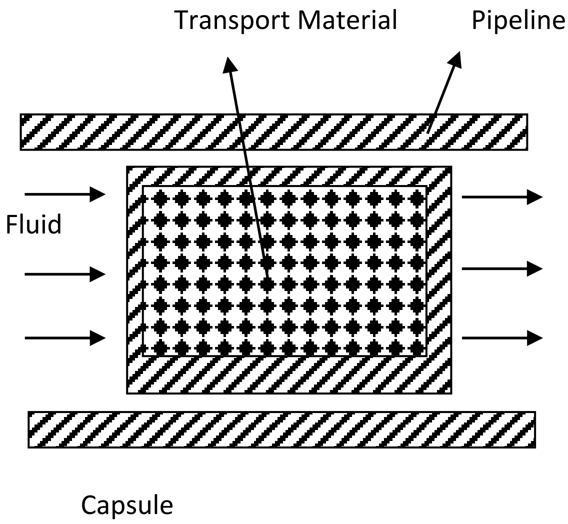


Figure (1): Capsule flow in a pipeline.

Experimental apparatus

An experimental system shown in figure (2) was designed and constructed to study the possibility of transporting sulfur by cylindrical capsules through the strategic crude oil pipeline by using capsular flow technology instead of transporting sulfur by train ,trucks…etc .

The experimental apparatus consists of the following parts:

1-Tanks

There are two tanks made of Aluminum, one is the supply tank (120 liters) which supplies crude oil to the pipeline through the centrifugal pump, the other is the discharge tank (60 liters) which is used for collecting the capsules.

2-Pump

A multi-stage centrifugal pump of $3m^3/hr$ volumetric flow rate, 45m maximum head and 740 Watt maximum power, was used for pumping the crude oil or water.

3-Turbine flow meter

A turbine flow meter was used in the position shown in figure (2) for reading the volumetric flow rate of the crude oil pumped.

4-Control valves

The valves are shown in figure (2). They are used to direct the main flow through the bypass line. The capsule is pushed manually into the lock formed by two ball valves (V.4 and V.5) in the upstream section of the pipeline. The main flow of the crude oil should be bring behind the capsule by four valves simultaneous opening.

5-Pipeline

The pipeline was constructed from P.V.C. material and was 9 m long and 50mm outside diameter.

6-Manometer

A four manometers was installed in the position shown in figure (2), used for reading the pressure difference caused by passing a train of cylindrical capsules filled with sulfur.

7-Carrier fluid

The carrier fluids that were used for transporting sulfur by capsules through the pipeline either Iraqi crude oil ,which has Dynamic viscosity of $6.919x10^{-3}$ N.s/ m^3, and density of 871 kg/m^3 at 25°C, or water which has Dynamic viscosity of $1.09x10^{-3}$ $N.s/m^3$, and density of 1000 kg/m^3 at 25 °C.

8-Capsules

A typical cylindrical flat-ended capsules is shown in figure (3) was used for this study, which has different aspect ratio and diameter ratio are listed in Table (1).Capsules were made of P.V.C. material and plastic flat-ends which could be fitted in any combination.

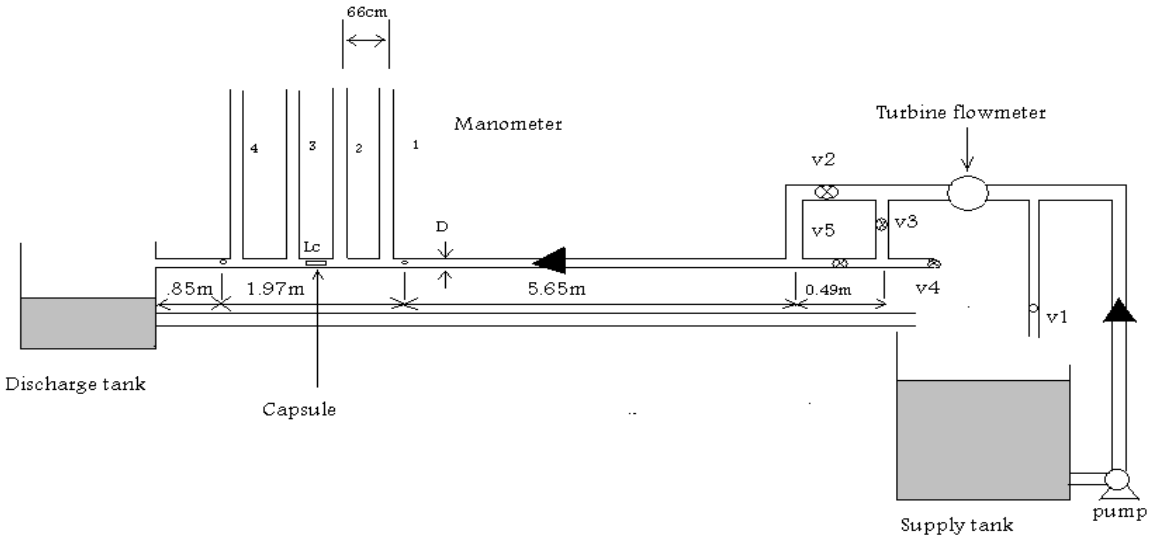


Figure (2): Schematic diagram of the experimental apparatus.

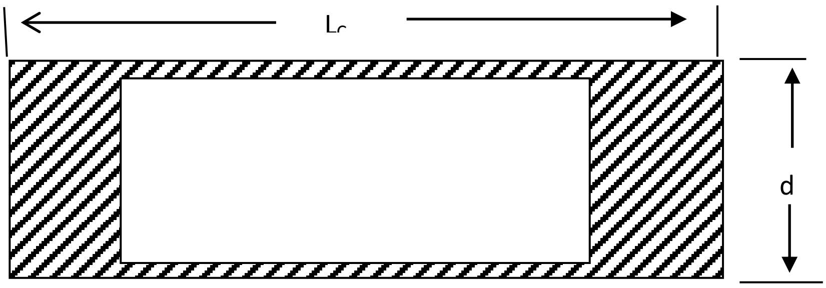


Figure (3): Flat-ended cylindrical capsule Body

Table (1): Capsule diameter ratios, length/diameter ratios and net weight of sulfur transported for the flat-ended cylindrical capsules

Capsule Diameter(d) (mm)	Diameter Ratio(k) d/D	Capsule Length/diameter Ratio (L_C/d)
32	0.69	6.53, 3.97, 2.2
25	0.54	7.2, 4.4, 2.28
20	0.43	8.9, 5.4, 2.75
16	0.35	13.43, 8.5, 4.44

The Measurements

The measurements are outlined as follows:

1- At the beginning of each run, air is vented to avoid blockage in the hose of the manometer.

2- When the flow reaches the steady state, measurements are taken as follows :

   a. Measurement of flow velocity for the flow of water.
   b. Measurement of pressure gradient for the flow of fluid alone.
   c. Introducing a train of capsules (five) manually (with k or Lc/d) by the following steps :
      i. Close V3 and V5 and then open V4.
      ii. Introducing the capsules to the lock formed between V4 and V5.
      iii. Close V4 and then open V5 and V3.
   d. Measurement of pressure gradient for passing a train of capsules at different diameters is taken.
   e. Measurement of pressure gradient for passing a train of capsules at different lengths is taken.
   f. The run is then repeated, but with different flow velocity.

3- All above procedures are repeated with the use of crude oil.

Results and Discussion

Results were obtained for pipe diameter, D= 0.046 m, diameter ratio, k=d/D capsule/pipe diameter which 0.54 and 0.69. L_c/d capsule aspect ratio, varied from 2.2 to 7.2, U_{av} average flow velocity for water or crude oil, ranging from 0.37 to 0.43 m/s.

Figure (4) is represented the relationship between the pressure head and distance (pipe length) for different diameter ratio and aspect ratio at constant average flow velocity of the water. The inversely proportional relationship between distance and pressure head is related to decrease the pressure force of the pump, and then will decrease the pressure head. The increase in aspect ratio and diameter ratio will give an increase in the pressure head because it will increase the weight of capsule, which lead to increase pressure head.

The effect of average flow velocity on the pressure head can be observed in Figures (5 and 6) in which the decrease in flow velocity decreases the pressure head for the flow of water alone, but increases the pressure head when increasing the aspect ratio and diameter ratio.

Figures (7, 8 and 9) are the same as Figures (4, 5 and 6) but using crude oil instead of water, from which we can see that the crude oil gives more pressure head than water.

Figure (10) is shown the relationship between the pressure gradient ratio (pressure gradient caused by passing capsules /pressure gradient for the flow of fluid alone$(\Delta P/L)_c/\Delta P/L)L$) with aspect ratio at different diameter ratio at constant average flow velocity of water, in which the increasing in aspect ratio and diameter ratio will increasing the pressure gradient ratio.

The effect of average flow velocity on the pressure gradient ratio can be observed in Figures (11and12) in which the decreasing in the average flow velocity will decreases the pressure gradient ratio for diameter ratio of 0.69,but increases the pressure gradient ratio for diameter ratio of 0.54.

Figures (13, 14 and 15) are the same as Figures (10, 11 and 12), but using crude oil instead of water, from which the crude oil gives less pressure gradient ratio than water.

Conclusion

The results could be summarizes as follows:

1- Capsules of diameter ratios of 0.35 and 0.43 are failure in the flow of capsules in a train, only can be transported singly.
2- The possibility of transporting sulfur by capsules in a train form can be achieved when the average flow velocity of water or crude oil is greater or equal 0.37 m/s.
3- The minimum pressure gradient ratio can be obtained for capsule length of twice its diameter.
4- The increase in diameter ratio causes an increase in pressure gradient ratio.
5- The decrease in average flow velocity decreases the pressure gradient ratio for diameter ratio of 0.69, and increases the pressure gradient ratio for diameter ratio of 0.54.
6- Crude oil gives less pressure gradient ratio than water, but it gives more pressure head than water.

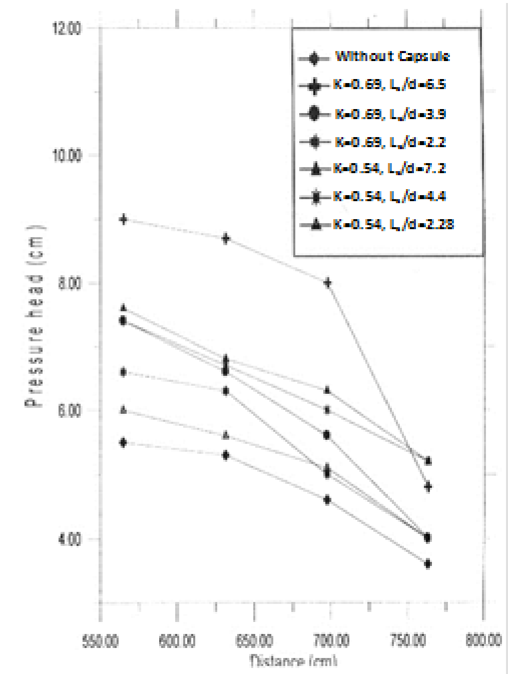


Fig. (4): Variation of pressure head with distance for the average flow velocity of 0.43 m/s(water)

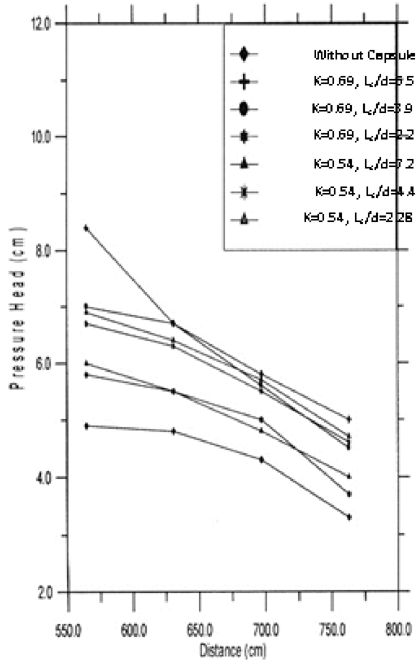


Fig. (6): Variation of pressure head with distance for the average flow velocity of 0.43 m/s (crude oil)

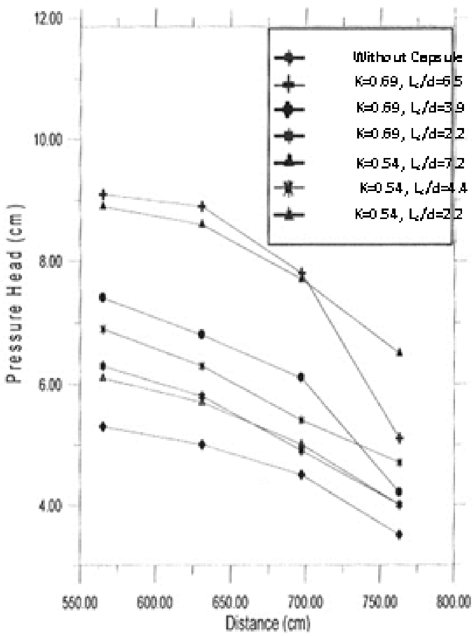
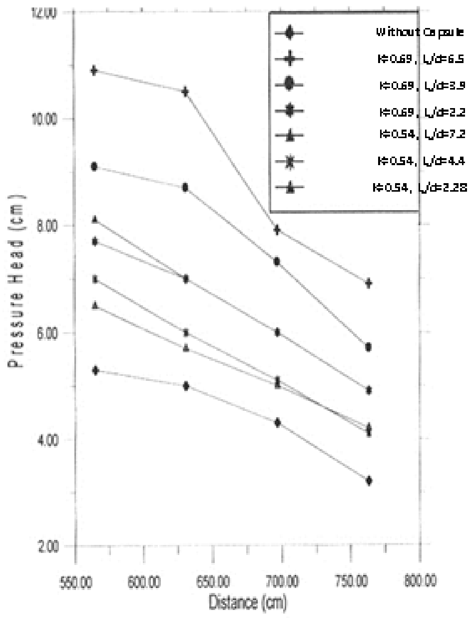


Fig. (5): Variation of pressure head with distance for the a verage flow velocity of 0.42M/s (water)



Fig(7): Variation of pressure head with distance for the average flow velocity of o.4 m/s (crude oil)

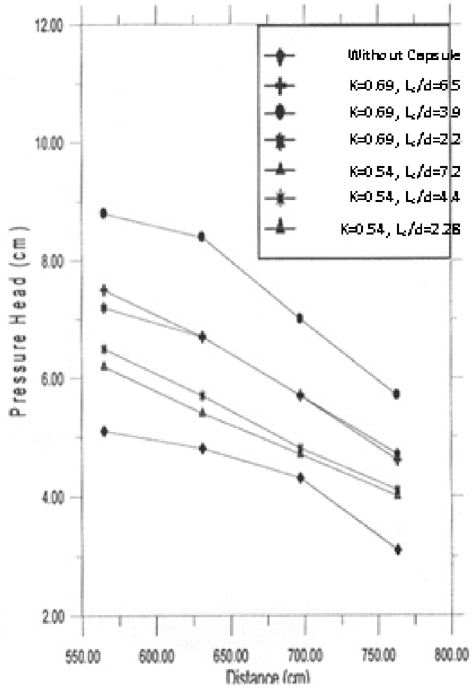


Fig. (8): Variation of pressure head with distance for the average flow velocity of 0.38 m/s (crude oil)

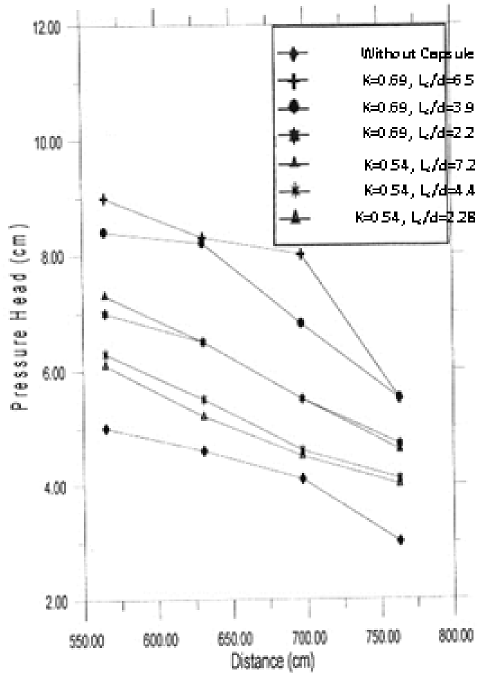


Fig. (9): Variation of pressure head with distance for the average flow velocity of 0.37m/s (crude oil)

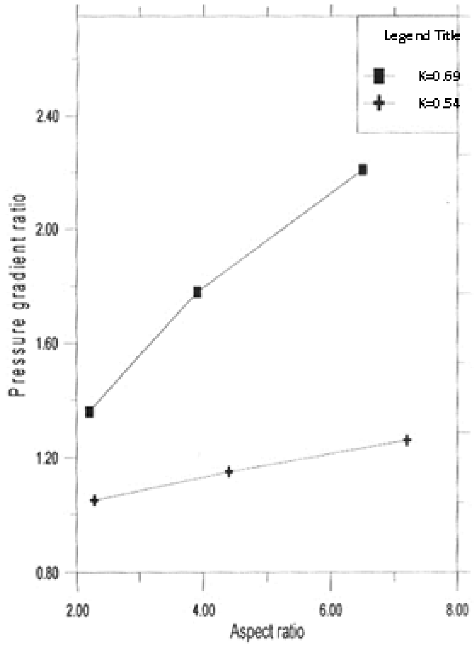


Fig. (10):Variation of pressure gradient ration with aspect ratio for the average flow velocity of 0.43M/S (water)

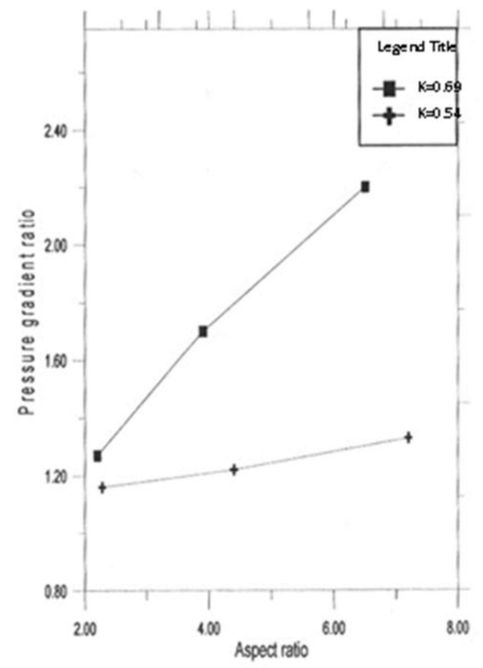


Fig. (11): Variation of pressure gradient ratio with aspect ratio for the average flow velocity of 0.42 m/s (water)

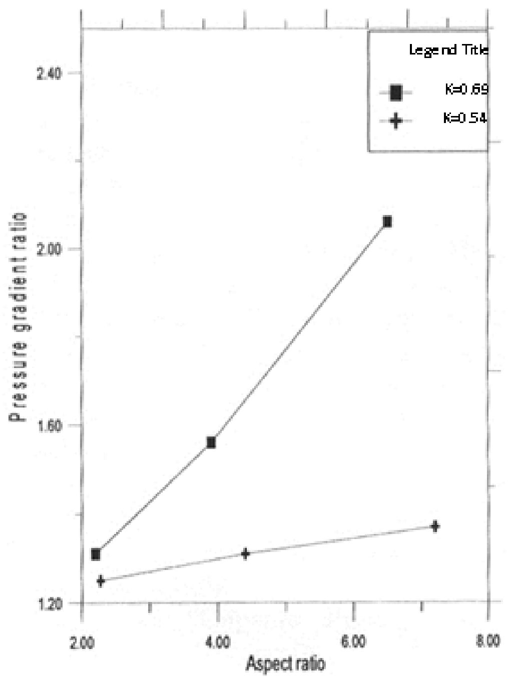


Fig. (12): Variation of pressure gradient ratio with aspect ratio for the average flow velocity of 0.4 m/s (water)

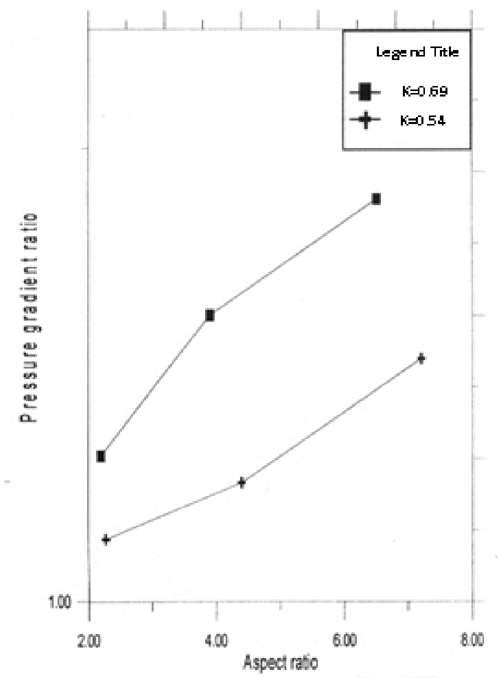


Fig. (14): Variation of pressure gradient ratio with aspect ratio for the average flow velocity of 0.39 m/s (crude oil)

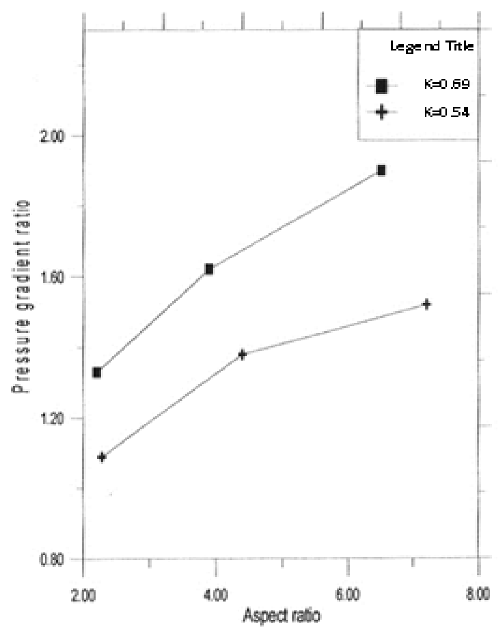


Fig. (13): Variation of pressure gradient ratio with aspect ratio for the average flow velocity of 0.4 m/s (crude oil)

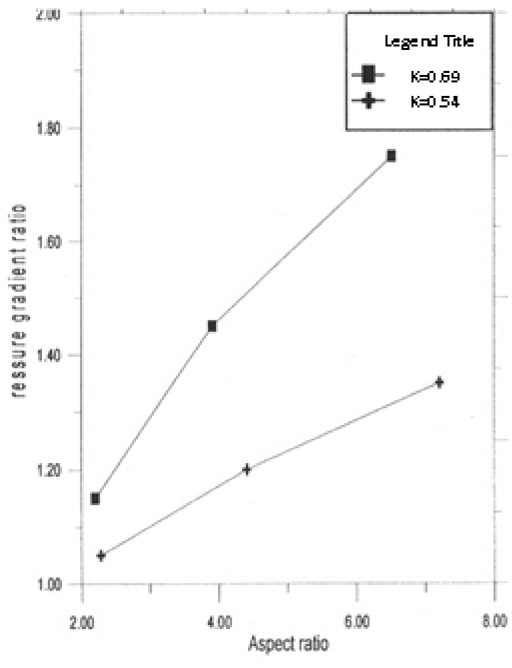


Fig. (15): Variation of pressure gradient ratio with aspect ratio for the average flow velocity of 0.37 m/s (crude oil)

References

Ellis, H. S. and Bolt, L. H., (1964) The Pipeline Flow of Capsules, Can. J. Chem. Eng., 42, 201

Ellis, H. S., (1964a) The Pipeline Flow of Capsules, Can. J. Chem. Eng., 42, 1

Round, G. F.and Bolt, L. H., (2009) An Experimental Investigation of The Transport in Oil of Single, Denser-Than Oil, Spherical and Cylindrical Capsules, Can. J. of Chem. Eng., 43, 197-205

Govier, G.W. and Aziz, K., (1972) The Flow of Complex Mixture in Pipes, Van Nostrand Reinhold, New York.

Hodgson, G.W. and Charles, M.E., (1963) The Pipeline Flow of Capsules, Can. J. Chem. Eng., 42, 43.

Jeansen,. E. J. and Bruse, J. G. (1970) Capsule Pipeline, British Hydrodynamics Research Association, Gramfield, Bedford, England.

Feng., D. D.and Joseph, J. (1995) Fluid Mechanics, Dynamic Simulation of The Motion of Capsule in Pipeline, 286, 201-227.

Liu, H. and Assadollahbaik, M., (1981) Feasibility of Using Capsule Pipeline to Transport Coal, J. Pipeline, 1, 295.

Liu, H., (2001) Capsule Pipeline Research Center, University of Missouri-Columbia, ://A:\392.htm.

Liu, H., (1981) Hydraulic Capsule Pipeline, J. Pipelines, 1, 11.

Marcu, M., (2000) Capsule Pipelines-History, //A:\Capsule Pipeline-History-1900-1999.htm.

Polderman, H. G. (1982) Design Rules for Hydraulic Capsule Transport Systems, J. Pipeline, 3, 123.

Gasner,R. G. and Raithby,G. D., (2009) Laminer Flow Between a Circular Tube and a Cylindrical Eccentric Capsule, Can. J. of Chem. Eng., 56, 176-180.

Thornton, A., (1972) The Hydraulic Transport of Solid in Pipes, New York.

Tomita, Y., Yamamoto, M. and Funatsu, K., (1986) Motion of a Single Capsule in a Hydraulic Pipeline, J. Fluid Mech., 171, 495.

Nomenclature

Parameter Definition	units
L_c Capsule length	(m)
L_c/d Capsule aspect ratio	(dimensionless)
K=d/D Diameter ratio	(dimensionless)
D=Pipe diameter	(m)
d=Capsule diameter	(m)
V1-V5 Valves	
U_{av}=Average flow velocity	(m/s)
$(\Delta p/L)_c/(\Delta p/L)L$=Pressure gradient ratio	(dimensionless)