PRESSURE DROP OF CuO-BASE OIL NANOFLUID FLOW INSIDE AN INCLINED TUBE

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ABSTRACT

An emprical study was carried out to study pressure drop in forced laminar nanofluid flow inside an inclined copper tube under constant heat flux condition at the outer wall.The CuO-base oil nanofluid in different nanoparticle weight concentration of 0.5%, 1% and 2% was produced by means of ultrasonic device in two steps method. In this study, the effect of tube inclination and nanofluid with different concentration are sudied.Results show that using nanofluid has slightly increased the pressure drop. Also, increase of tube inclination from zero (horizontal) to 30 degree at constant nanofluid concentration, the pressure drop decreased for Re<170.

KEYWORDS: *Nanofluid, Pressure drop, inclination, single phase, constant heat flux, experimental*

I. INTRODUCTION

Thermal load removal is a great concern in many industries including power plants, chemical processes and electronics. In order to meet the ever increasing need for Most of these methods are based on structure variation, vibration of heated surface, injection or suction of fluid and applying electrical or magnetic fields which are well documented in literature [1,2]. However, applying these enhanced heat transfer techniques are no longer feasible for cooling requirement of future generation of microelectronic systems, since they would result in undesirable cooling system size and low efficiency of heat exchangers. To obviate this problem, nanofluids with enhanced thermo-fluidic properties have been proposed since the past decade. Nanofluid is a uniform dispersion of nanometer-sized particles inside a liquid which was first pioneered by Choi [3].

Excellent characteristics of nanofluids such as enhanced thermal conductivity, long time stability and little penalty in pressure drop increasing and tube wall abrasion have motivated many researchers to study on thermal and flow behavior of nanofluids. These studies are mainly focused on effective thermal conductivity, phase change behavior, tribological properties, flow and convective heat transfer of nanofluids.

A wide range of experimental and theoretical studies has been performed on the effect of different parameters such as particle concentration, particle size, mixture temperature and Brownian motion on thermal conductivity of nanofluids. The results showed an increase in thermal conductivity of nanofluid with the increase of nanoparticles concentration and mixture temperature [4–7].Wen and

Ding [8] have studied Al2O3/water nanofluid heat transfer in laminar flow under constant wall heat flux and reported an increase in nanofluid heat transfer coefficient with the increase in Reynolds number and nanoparticles concentration particularly at the entrance region.
In addition, few works have studied friction factor characteristics and pressure drop of nanofluids flow besides the convective heat transfer. Xuan and Li [9] investigated the flow and convective heat transfer characteristics for Cu/water nanofluids inside a straight tube with a constant heat flux at the wall, experimentally. Results showed that nanofluids give substantial enhancement of heat transfer rate compared to pure water. They also claimed that the friction factor for the nanofluids at low volume fraction did not produce extra penalty in pumping power. In laminar flow, Chandrasekar et al. [10] investigated the fully developed flow convective heat transfer and friction factor characteristics of Al2O3-water nanofluid flowing through a uniformly heated horizontal tube with and without wire coil inserts. They concluded that for the nanofluid with a volume concentration of 0.1%, the Nusselt number increased up to 12.24% compared to that of distilled water. However, the friction factors of the same nanofluid were almost equal to those of water under the same Reynolds numbers.Ben Mansour et al [11] has numerically investigated Water-AL_2O_3 nanofluid inside an inclined conjugated tube . By passing laminar nanoflouid flow in heated tube, they found that using the nanofluid increase the bouyancy of secondary induced flow and decrease friction at the inner wall. Recently,the effects of adding nano diamond with different concentration to engine oil on the pressure drop inside the microfin tube under constant heat flux at the outer wall and laminar nanofluid flow conditions was investigated by Akhavan-behabadi et al[12]. The results show an increase in pressure drop with enhances nano particle concentration.
Review of literature shows that only a few articles have considered the pressure drop of nanofluid flow inside an inclined tube other than horizontal tube.
In the present work, the simultaneous effects of adding nanoparticles to the base fluid and tube inclination on flow pressure drop are studied. A new suspension of nanofluid namely CuO-Base oil is selected for this investigation. The main reason for choosing CuO-base oil nanofluid is that copper oxide nanoparticles are used as additives for industrial oils such as engine oil, heat transfer oil and lubricating oil in order to remove heat from high heat flux surfaces.These additives also have shown anti wear and anti friction characteristics result in reducing pressure drop, due to their spherical shapes [13, 14]. Also, to study on the behavior of CuO nanoparticles more effectively, a type of oil with no additives (SN-500) is used. This type of oil is the basic component of the industrial oils. It is apparent that the effect of nanoparticles on heat transfer performance of the specified oil can be generalized to the mentioned industrial oils for the sake of heat transfer enhancement.
This study results lead the maker to manufacture a smaller and more efficient non horizontal heat exchanger with various industrial application such as vertical heat exchanger instead of radiator in vehicle and modern thermal powerplants that work with lower pumping power of nanofluid flow.
The next sections will give useful information about CuO nano particle, producing method of CuO-base oil nanofluid with different concentrations, experimental apparatus, measurment tools and test section.in addition, in the result section, validation of experimental and theoretical data are checked for base oil at zero and 30 degrees of tube angles.

II. NANOFLUID PREPARATION

The solid particles used in this study were CuO. They were produced with an average particle size of 40 nm and purity of 99% by means of chemical analysis method. The SEM (scanning electron microscope) micrograph of the CuO nanoparticles and the XRD (X-ray diffractions) Pattern are shown in Figs. 1 and 2, respectively. Reflections in the XRD pattern can be attributed to the CuO using JCPDS (Joint Committee on Powder Diffraction Standards). Also it can be seen from the SEM image of the sample that the majority of nanoparticles are in the form of large agglomerates before dispersion.

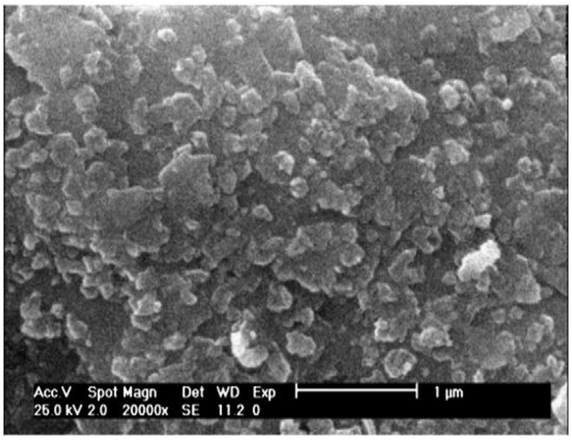

Figure 1, SEM image of CuO nanoparticles

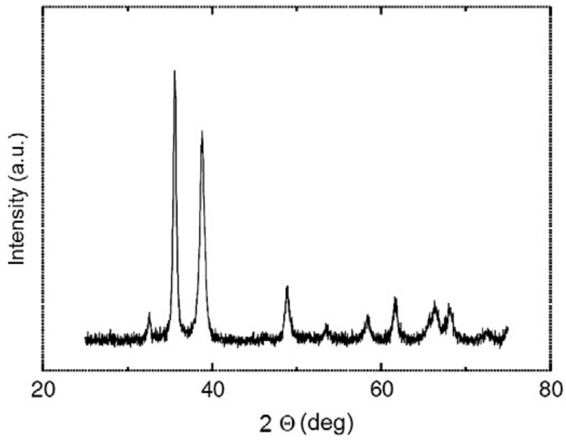

Figure 2, XRD analysis of CuO nanoparticles

Nanofluids with particle weight concentrations of 0.5%, 1% and 2% were prepared by dispersing specified amount of CuO nanoparticles in base oil using an ultrasonic processor (Hielscher Company, Germany) generating ultrasonic pulses of 400 W at 24 kHz frequency.

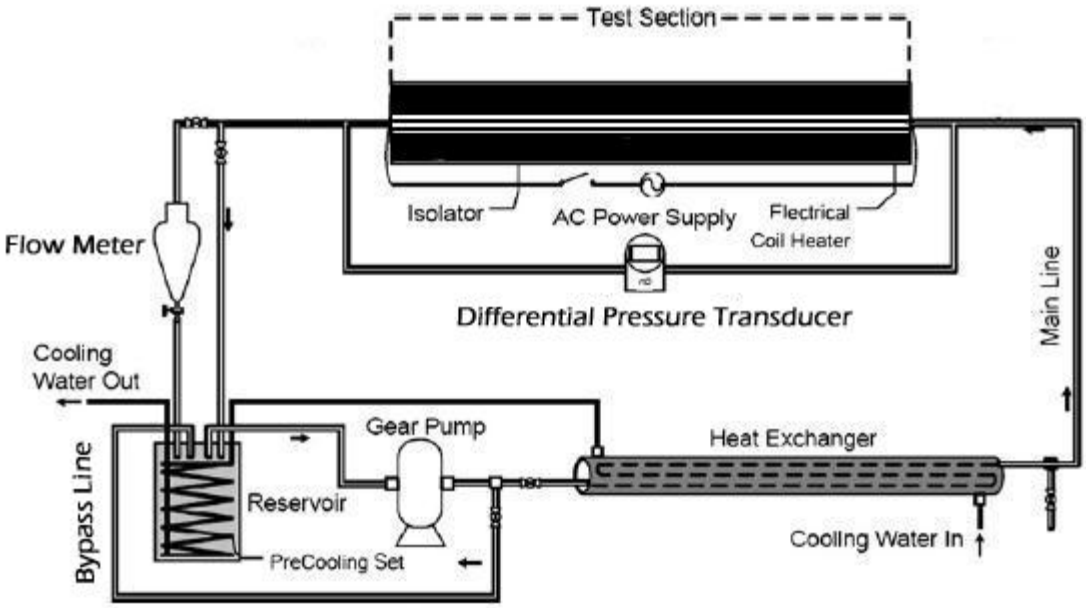

Figure 3. Schematic diagram of experimental apparatus

This device is used to break large agglomerates of nanoparticles in the fluid and make stable suspension. No surfactant was used as they may have some influence on the effective thermal conductivity of nanofluids. It was observed with naked eyes that the nanofluids were uniformly dispersed for 24 h and the complete sedimentation occurred after a week.

III. EXPERIMENTAL APPARATUS

The schematic diagram of experimental apparatus is shown in Fig. 3. The flow loop consists of a rotary test section, heat exchanger, reservoir, gear pump, flow meter and flow controlling system. Fluid leaving the test section enters the flow meter, cools partially in the reservoir and then pumps through a heat exchanger in which water is used as cooling fluid, and again enters the test section.
The test section can be rotated from zero degree (horizental) to 90 degree (vertical).
In this study, nanofluids with different particle weight fractions of 0.5%, 1% and 2% are used as the working fluids. Also, pure base oil is used for the sake of comparison. The experimental apparatus is designed to measure pressure drop characteristics of working fluids over the length of the test section in horizontal and inclined (+30 degree) tube state.A round copper tube of 12.7 mm outer diameter, 0.9 mm wall thickness and 1200 mm length is used. Fig. 4 shows the cross sectional area of the applied rotary test sections.
The nanofluid flowing inside the test section is heated by an electrical heating coil wrapped around it to generate constant heat flux. Flow measuring section is consisted of a 1 lit. glass vessel with a valve at its bottom. Flow rate is measured directly from the time required to fill the glass vessel. To adjust the flow rate, the valve of the bypass line is used. The total pressure drop of fluid flow along the test section is measured by high precision differential pressure transmitter (PMD-75). As it is shown in Fig. 3, this instrument measures the pressure difference between the inlet and outlet of test section. Provisions are also made to measure all the other necessary parameters. The ranges of operating parameters are defined in Table 1.

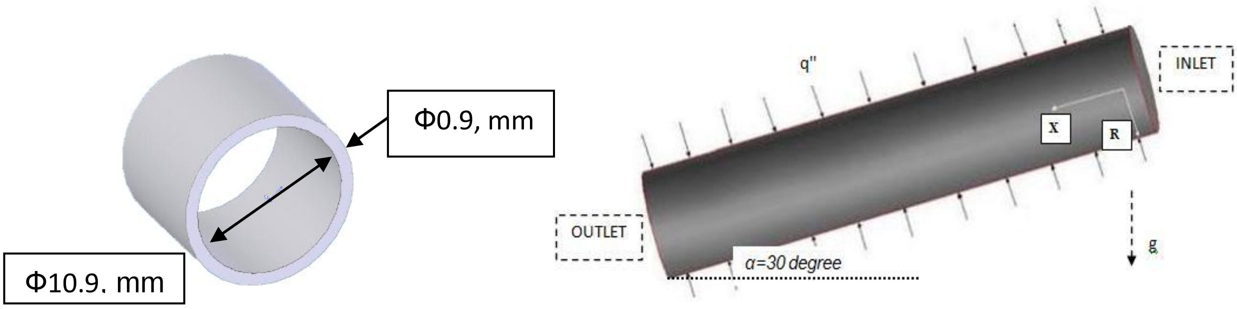

Figure 4. Cross section and inclination of rotary test section

IV. DATA COLLECTION AND DATA REDUCTION

All the physical properties of base oil and nanofluids are measured using accurate measuring instruments. To measure the density of the base oil and nanofluids with different weight fractions at different temperatures, SVM3000 instrument (made in Austria) is used. The rheological behavior and viscosity of the CuO–base oil nanofluid was measured using Brookfield viscometer (DV-II+Pro Programmable Viscometer) with a temperature controlled bath, supplied by Brookfield engineering laboratories of USA.

Table 1. The range of operating parameters

Parameter	Range
Nanofluid	CuO–base oil
Nanoparticles weight concentration, %	0–2

Heat flux, W/m2	3200
Reynolds number	10–170
Mass flow rate, kg/s	0.008–0.048
Tube length, mm	1200
Outer diameter, mm	12.7

V. RESULTS AND DISCUSSION

5.1. Validation check

In order to verify the accuracy and the reliability of the experimental System, the pressure drops are experimentally measured using base oil as the working fluid before obtaining those of oil based CuO nanofluids. The experiments are conducted within the Reynolds number of 170. Due to flow low Reynolds number, hydrodynamically fully developed laminar flow is assumed for theoretical calculations.Also, because oil has got high Prandtl number, the flow is in the thermal entrance region (x/D<0.05RePr). Experimentally measured pressure drop is compared with the pressure drop obtained from the following theoretical equation.

$$\Delta p(th) = \frac{32\mu LV}{D^2} \quad (1)$$

In which, μ is measured at the average of inlet and outlet temperatures. Fig. 6 show the variation of the theoretical values for pressure drop along the test section versus measured pressure drop.

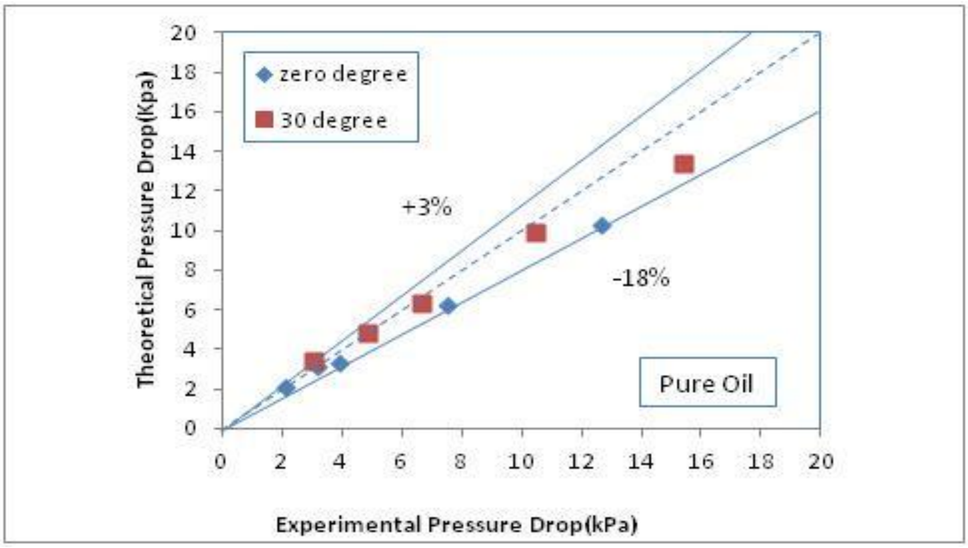

Figure 6. Comparsion betweem theoretical and experimental pressure drop of base oil flow inside round tube at zero and 30 degree of tube inclination.

As it can be seen from Fig. 6, the deviation of the experimental data from the theoretical one is within −18% and +3%. There is a good agreement between theoretical and experimental data.then the pressure drop parameter of CuO-base oil nanofluids flowing inside round tube in horizontal and inclined tube state are investigated experimentally for laminar flow under constant heat flux condition.Note that in the following results, pressure drop data is not achieved under exactly the same Reynolds numbers. This is because the viscosity of oil-based nanofluid is so dependent on fluid temperature and particle weight fraction.

5.2. PRESSURE DROP RESULTS

The measured pressure drop along the round tube for the flow of pure oil and CuO–base oil nanofluids with different weight fractions as a function of Reynolds number in horizontal an inclination state are given in Fig. 7, 8.

The results show that, with increase nanoparticle concentration, the pressure drop increase in both

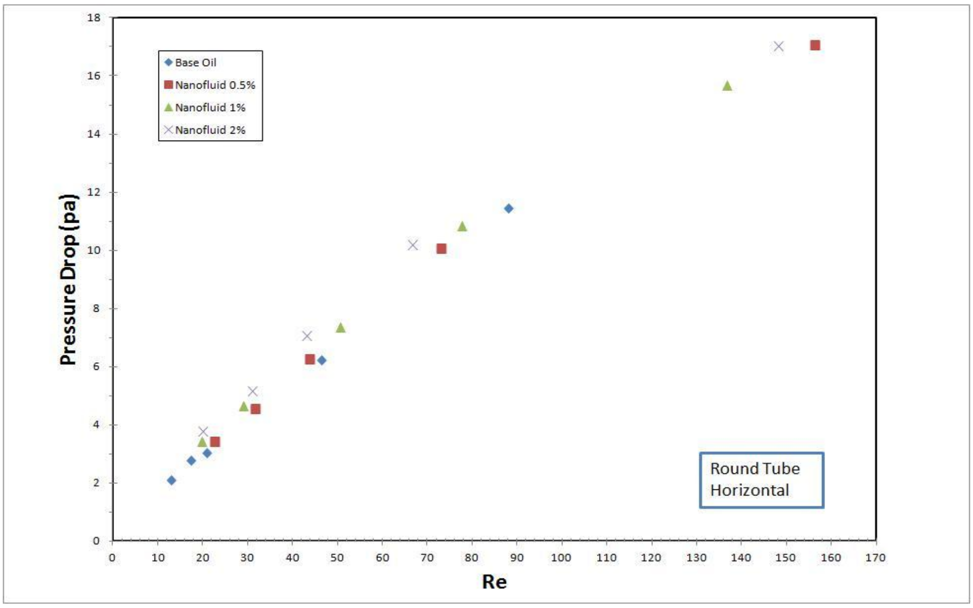

Figure7. Variation of pressure drop with Reynolds number for base oil and nanofluids flow inside the horizontal tube at constant heat flux**.**

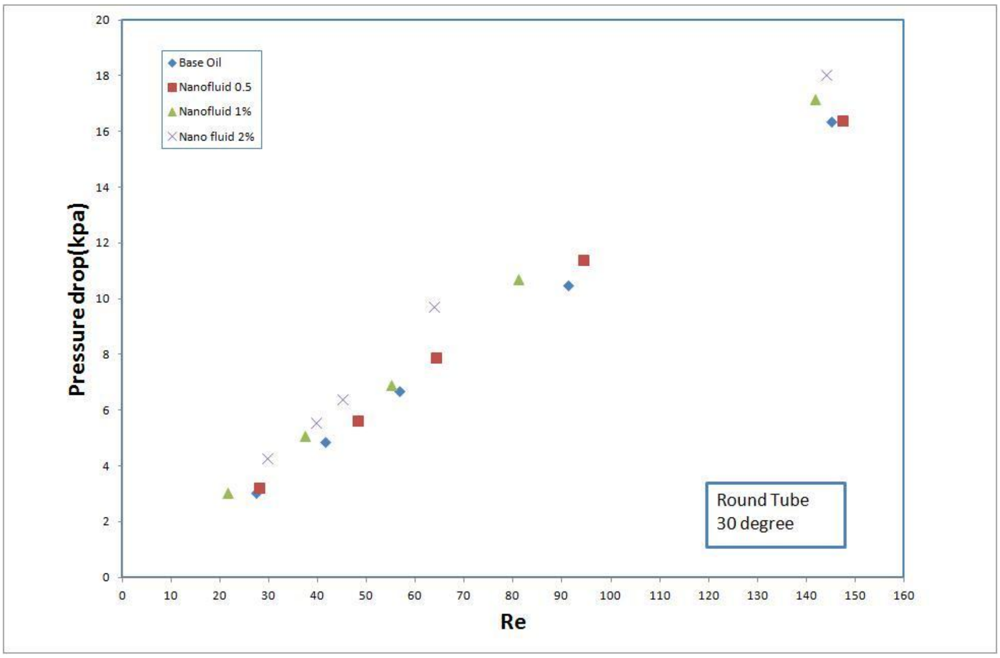

Figure 8. Variation of pressure drop with Reynolds number for base oil and nanofluids flow inside the inclined tube at constant heat flux**.**

horizontal and inclined tube. There is not a noticeable increase in pressure drop of nanofluid with 0.5% wt. particle concentration compared to that of pure oil flow. This enhancement trend tends to continue for the nanofluids with higher weight fractions.In addition, the results show that for the round tube the maximum pressure drop increasing is achieved when nanofluid with 2% wt. concentration is used instead of base fluid in both test section position. The variation of pressure drop versus Reynolds number for the 0.5% wt. nanofluid flow inside round tube at constant heat flux at zero and 30 degree tube inclination are depicted in Fig. [9]. the obtained results show that the tube inclination have decreased pressure drop remarkably compared to that of horizontal tube at low Reynolds number.This can also lead to wall shear stress decreasing which results in pressure drop decline.

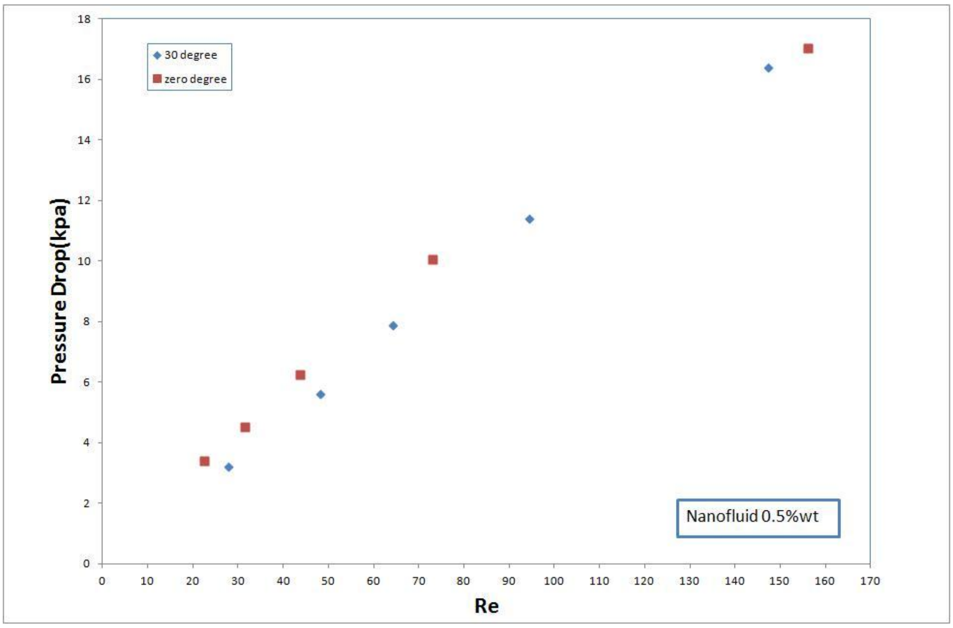

Figure 9. Comparison of variation of pressure drop with Reynolds number for horizontal tube with inclined (30 degree) tube at the constant nanofluid concentration (0.5%wt).

VI. CONCLUSION

In the present study, pressure drop characteristics of the pure base oil and CuO–base oil nanofluid flow inside in horizental and inclined tube are investigated.

1. For a given tube and at a same flow conditions, there is an increase in pressure drop of nanofluids compared to that of base liquid.

2. At the same flow conditions and for a given nanofluid with constant particle concentration, tube inclination decreases the pressure drop compared to that of the horizontal tube, significantly.

In the future study, a wide range of study shall be performed on the heat transfer and pressure drop of the various nanoparticles such a MWCNT. in the different condition because of complicated behavior of nanofluid.furthermore, the effects of tube inclination with non-circular cross section such a flattened tube can be studied.

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