FLUID FLOW AND HEAT TRANSFER ANALYSIS FOR POWER LAW FLUIDS IN CIRCULAR CYLINDER

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To my beloved parents, wife and child

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ABSTRAK

Dalam tesis ini, persamaan momentum dan haba teori pemindahan untuk cecair *"Power-Law"* bukan Newtonian dalam silinder diselesaikan secara berangka. Model kondenser yang mudah digunakan untuk menganalisis kesan kelakuan cecair *"Power-Law"* dalam keadaan operasi industri. Keputusan ke atas struktur terperinci aliran dan suhu dibentangkan menggunakan pelbagai parameter berikut:- *"Power-law"* nombor ($0.4 < n < 1.8$), dan *Reynolds* nombor ($1 \leq Re \leq 10^4$). Pada nombor Reynolds yang rendah, cecair masih melekat pada permukaan silinder. Ini bermakna ciri pemindahan haba yang baik bagi nilai n kurang daripada 1 (iaitu Bendalir Newtonian). Bila bilangan Reynolds bertambah, fenomena pemindahan haba yang lebih tinggi masih diperhatikan tetapi tidak sebaik nombor Reynolds yang rendah.

ABSTRACT

In this thesis, equations using momentum and heat transfer theory for Power-Law, non-Newtonian fluids over circular cylinder are being solved numerically. A simple model of condenser is used to analyze the effect of the Power-law fluids behavior in industrial operating conditions. Results on the detail structure of the flow and temperature are presented using the following parameter range: - Power-law index ($0.4 < n < 1.8$), and generalized Reynolds number ($1 \leq Re \leq 104$). At low Reynolds number, the flows remain attached to the surface of the cylinder. This implies higher heat transfer characteristic for value of n less than 1 (ie. Newtonian Fluid). As the Reynolds number increases, higher heat transfer phenomena are still observed but not as good as those of low Reynolds.

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LIST OF ABBREVIATIONS

NOMENCLATURE

C_D	-	Total drag co-efficient
C_{Df}	-	Friction drag co-efficient
C_{Dp}	-	Pressure drag co-efficient
C_f	-	Skin friction co-efficient $\equiv 2\tau_w/\rho U^2{}_{app}$
C_p	-	Pressure co-efficient $\equiv 2\Delta P/\rho U^2{}_{app}$
c_p	-	Specific heat of the fluid (J /kg.K)
D	-	Cylinder diameter (m)
K	-	Thermal conductivity (w/m.K)
h	-	Average heat transfer co-efficient (w/m^2.K)
m	-	Consistency index for non-Newtonian Viscosity (Pa.s^n)
n	-	Power-law index
Nu_D	-	Averange Nusselt number based on the diameter of the cylinder $\equiv hD/k_f$
Pr_p	-	Prandtl number for power-law fluid $\equiv (U_{app}D\alpha)Re_{DP}{}^{-2/(n+1)}$
P	-	Pressure (N/m^2)
q	-	Heat flux (W/m^2)
Re_{DP}	-	Generalized Reynolds number based on the diameter of the cylinder $\equiv D^n\rho U_{app}^{2-n}/m$
s	-	Distance along the curve surface of the cylinder measure from the forward stagnation point (m)
T	-	Temperature (˚c)
U_{app}	-	Approach Velocity (m/s)
$U(s)$	-	Potential flow velocity just outside the boundary layer $\equiv 2U_{app}\sin\theta$ (m/s)
u	-	x-component of velocity in boundary layer (m/s)
v	-	y-component of velocity in boundary layer (m/s)

GREEK LETTERS

α	-	Thermal diffusivity (m^2/s)
δ	-	Hydrodynamic boundary-layer thickness (m)
δ^*	-	Displacement thickness (m)
θ	-	Momentum thickness (m)
δ_T	-	Thermal boundary-layer thickness (m)
y	-	Distance normal to and measured from the surface of the circular cylinder (m)
λ	-	Pressure gradient parameter
μ	-	Absolute viscosity of the fluid (Ns/m^2)
v	-	Kinematic viscosity of the fluid (m^2/s)
ρ	-	Density of the fluid (kg/m^3)
τ	-	Shear stress (N/m^2)
Θ	-	Angle measured from stagnation point (rad)
ζ	-	Ratio of the thermal and hydrodynamic boundary layer $\equiv \delta_T/\delta$

SUBSCRIPTS

a	-	Ambient
f	-	Fluid or Friction
H	-	Hydrodynamic
p	-	Pressure
s	-	Separation
T	-	Thermal or Temperature
w	-	Wall

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Air conditioning is one of the most successful creation that human being had done. The pioneer of electrical air conditioning is invented by Willis Carrier which is being implemented in one of the cinema in New York. The problem arises when weather is too hot for the audiences to watch a movie during summer period.

To date, there are many air conditioning system is being invented. The most common air conditioning system which used in domestically is single and multi split unit system. For commercial usage, air conditioning system which are being used are such as water cooled chiller, air cooled chiller, variable refrigerant flow system, water cooled package and etc. Offices and shopping mall are most likely adopting water cooled chiller system due to the efficiency of the air conditioning system and power consumption. In construction industry, heating, ventilation and air conditioning system is known as HVAC.

Water cooled chiller system shall consist of the following main items such as cooling tower, condenser pumpsets, chiller, chiller pumpset and etc. The main focus shall be on the chiller system since it is the heart of heat transfer process. The chiller is comprises of two (2) major component which is the evaporator and condenser. The focus in this study shall be on the condenser side. A shell and tube condenser operates by guiding condenser water with higher temperature into the shell and across the baffle tube which have refrigerant running in the tube and exits through the other side of the shell.

According to Malaysia government construction sector, JKR design code and guidelines for air conditioning system, the optimum operating temperature for condenser water system shall have 87˚F for chilled water return and have 97˚F for condenser water supply. In such, there will be a difference of $\Delta T = 10˚F$. Conventionally, the fluid which is implemented into the system is mostly treated water. This is due to it cost and availability in the market.

Fluid can be categorized into two different ways either according to the response to the externally applied pressure or according to the effects of produce under the effect of shear stress. When comes to classification, it leads to the fluid either be “compressible” or “incompressible” where the volume of the fluid dependent on pressure applied. Compressible fluid will usually relates to gaseous due to its flow characteristic, liquids shall usually relates to incompressible due to the response of shear

When comes to classification of fluid behavior, it can be categorized into Newtonian fluid and also non-Newtonian fluid. When both types of fluids are monitored, the basic component being studied is viscosity. The common value, n for Newtonian fluid is equals to 1 where shear stress is usually direct proportional to the shear rate. For non- Newtonian fluid, η is the apparent viscosity of the fluid where it is not constant. The value power-law index, n for non-Newtonian fluid is either more than one ($n > 1$) or less than one ($n < 1$).

According to Oswald-de Waele equation for Power-Law fluid, the shear stress can be rewritten as Eqn.(3):-

$$\tau = -\eta \left(\frac{\partial u}{\partial y}\right)^{n} = \left[\eta \left(\frac{\partial u}{\partial y}\right)^{n-1}\right]\left(-\frac{\partial u}{\partial y}\right) \tag{3}$$

where $\eta \left(\frac{\partial u}{\partial y}\right)^{n-1}$ is the the effective viscosity, μ_{eff}.

(4)

For Non-Newtonian Power-Law, viscosity of the shall be based on the equation as in Eqn (5):-

$$\eta = \mathrm{k}\left(\frac{\partial u}{\partial y}\right)^{n-1} exp\left[\alpha\left(\frac{1}{T - T_o} - \frac{1}{T_\alpha - T_0}\right)\right] \tag{5}$$

When flow behavior index, n plays into the picture, these fluids are known to be Power-Law fluid and can be categorized into different group as such where $n < 1$ is known as Pseudoplastic fluid and $n > 1$ is known as Dilatant fluid.

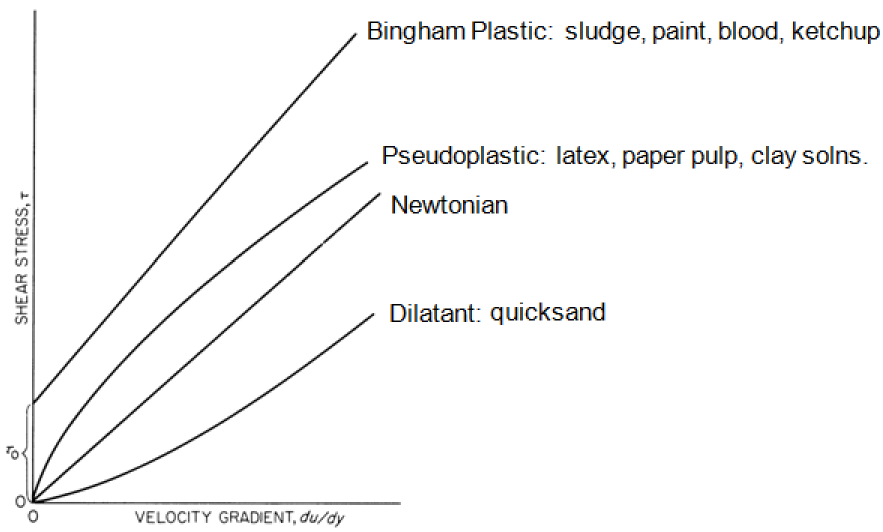

Figure 1:- Shear stress versus velocity gradient for Newtonian and non-Newtonian fluid.

Pseudoplastic fluid is also known as shear-thinning fluids where they have lower apparent viscosity, η at higher shear rates. However for Dilatant fluid, it is known as shear-thickening fluid where the apparent viscosity, η increase with higher shear rate. Most non-Newtonian fluids are known to be in Pseudoplastic form compare to Dilatant fluid where it is less common and rare. Many researcher had performed studies using Newtonian fluids either using, numerical method, experiment method and also theoretically. However, limited approached being conducted to study the behavior of fluid flow and heat transfer using power-law fluid.

However in recent study, Avinash Chandra (2011) highlighted that power-law fluids are widely being used in polymer food, pharmaceutical sectors, mineral processing industry, personal care products, agricultural chemical and etc. The study of momentum and heat transfer characteristic of cylinders in fluid acts as an important criteria with the domain of transport phenomena.

P.Koteswara Rao (2011) highlighted that the most common type of non-Newtonian fluid which studied in industry is the shear thinning fluid. Typical example of novel heat exchangers, cooling of electronic components, use of square bars as flow dividers to form weld lines in engineering application in continuous thermal treatment of food stuff. The apparent viscosity of power-law fluid can decrease in several orders of magnitude from a very high value at low shear rates to vanishingly small value at high shear rates which encountered in pipes and pump flow. In two dimensional studies, it gives rise to flow field where the effective rate of deformation varies from point to point. Many material of industrial application notably polymeric system (melts and solutions) and multi-phase systems like foams, emulsions and slurries display a range of non-Newtonian characteristics including shear dependent viscosity, yield stress and visco-elasticity. It is useful in other application such as cross-section tubular, pin-type and in other novel designs of compact heat exchangers, in novel design of mixing impellers and in rake filters used of non-newtonian slurries.

Amir Nejat (2012) highlighted that force convection is suitable for removing heat generated system such as electronic devices. Maximizing heat transfer and minimizing the pressure drop is ideal for cooling system. Force convection using moving fluid seems to be a reasonable method for removing heat generated from system. Heat transfer per unit area of fully developed laminar flow in a channel increases with a decrease in cross-section of the channel. It is important for the selection of the cooling fluid (coolant) and the appropriate arrangement of elliptical cylinder for range of low and moderate Reynolds number.

Vijaya K.Patnana (2010) highlight that flow past a circular cylinder represents a classical problem in fluid mechanics. Non-Newtonian fluids being applied in many industrial applications such as the flow in tubular and pin-type heat exchanger, in the use of thin wires as measuring probes, in thermal processing of food particles. In view of so-called “structured” substance of multi-phase nature and high molecular weight encountered in industrial practice (pulps and paper suspensions, food, polymer melts and solutions, foams, micellar solution and etc.) display shear-dependent flow behavior. Subjected to their high viscosity level, it is commonly encountered in laminar flow condition in processing such material.

1.2 Research Objective

The objective of this thesis is:

1) To analyze fluid flow and heat transfer behavior using power law fluid across the Shell and Tube evaporator.
2) Analytical method will be employed.
3) Drag and heat transfer co-efficient will be determined.

1.3 Problem Statement

Power consumption for chiller system is dependent on the refrigerant cycle which is plotted in the Pressure- Enthalpy curve. Workdone is measure using the area within the refrigerant cycle to measure power consumption. Power consumption for chiller can be reduced by either reducing the pressure lift of chiller water supply or the condenser water return.

Many types of fluids are being applied as a coolant. However, these fluids are mostly Newtonian fluid. Introducing power-law fluid (non-Newtonian) different n-term of power-law fluid will be considered into the condenser side instead of the chiller side.

Boundary condition of the model will be selected and therefore will affect the result of fluid flow and heat transfer. The aforementioned parameters and properties will be further discussed in later chapter.

1.4 Scope of Research

This thesis is to conduct a research on power-law fluid across shell and tube condenser by integrating the information of power law fluids into the system. Heat transfer and fluid flow behavior are indentified, verify and validate. The scopes of this thesis are as follows,

i) Identification type of Power-Law fluid.
ii) Development of model
iii) Identification of power-law properties.
iv) Analysis of the power-law characteristics.
v) Analytical and numerical computation on heat transfer and fluid flow.
vi) Analysis of heat transfer and fluid flow for power-law fluid.
vii) Obtaining the effects of power-law fluid which incorporated into the model.

1.5 Organization of Thesis

To complete this project, the following steps are required to be implemented,

i) Data collection from the published journals.
ii) Selection of power-law fluid.
iii) Setting of boundary conditions.
iv) Numerical analysis of fluid flow and heat transfer on circular cylinder.
v) Computational of velocity and temperature profiles using Matlab.
vi) Repeat steps (iii) to (vi) for different power-law fluid.
vii) Discuss the fluid flow and heat transfer across circular cylinder model.
viii) Conclusion

A weekly activity of this thesis has been presented in Gantt chart and appended in Appendix 1 and 2 for thesis 1 and 2 respectively.

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