

Lecture Notes in Mechanical Engineering

Anil Kumar

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Surendra Singh Kachhwaha

Prashant Kumar Jain *Editors*

# Recent Advances in Mechanical Engineering

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# Lecture Notes in Mechanical Engineering

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Surendra Singh Kachhwaha · Prashant Kumar Jain  
Editors

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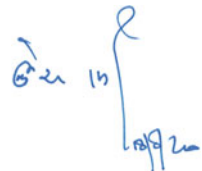
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# Foreword

I am pleased to know that an International Conference on “Recent Advances in Mechanical Engineering” (RAME 2020) is being organized by Department of Mechanical Engineering, Delhi Technological University (DTU), on September 18 and 19, 2020. I welcome all the delegates and participants across the globe for participating in RAME 2020 conference at DTU. I am sure that RAME 2020 conference will bring together the national and international talents.

The role of mechanical engineering is inevitable to improve productivity, product quality and safe working environment in the applied fields for the society at large. The conference shall provide excellent opportunities for researchers, scientists and industrialists to share and converse on the latest developments in the areas of mechanical engineering. The publication of the conference proceedings in *Lecturer Notes in Mechanical Engineering*, Springer, will give a new benchmark and more insight to the R&D initiatives in these areas. I also hope that the conglomeration of eminent experts will highlight the importance of research and innovation and discuss the best global practices.

I congratulate the organizing team of RAME 2020 conference and wish that the conference will be a grand success and help in branding Delhi Technological University as a leading research university.

A handwritten signature in blue ink, appearing to read 'Yogesh Singh', with a date '13/09/20' written below it.

Prof. Yogesh Singh  
Vice-Chancellor  
Delhi Technological University  
New Delhi, India

# Preface

Mechanical engineering is the application of physical principles of science and engineering to the creation of useful systems, devices, objects and machines. This basic perception of mechanical engineering still holds good, while it has evolved into various new fields. Mechanical engineering is thus deep rooted in to a vast engineering canvas and is in the service of mankind at all levels. Therefore, there is also a need to understand the design principles for environment, life-cycle design and sustainable development.

It is our pleasure to present the academicians and scholars, the proceedings of the research papers scheduled for presentation at the 2nd International Conference on “Recent Advances in Mechanical Engineering” during 18–19 September 2020 at the Department of Mechanical, Production and Industrial and Automobile Engineering and Centre for Energy and Environment, Delhi Technological University (*Formerly Delhi College of Engineering*), Delhi-110 042 (India). This conference is in series with earlier international conference RAME-2016 organized by the Department of Mechanical Engineering, Delhi Technological University (Formerly Delhi College of Engineering), Delhi-110 042 (India). The conference was very well received, both by the industry and academia.

The core organizing committee for organizing RAME-2020 is:

- **Chief Patron:** Prof. Yogesh Singh, Hon’ble Vice-Chancellor
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The proceeding consists of papers contributed by leading academicians, research scholars and experts from the industries. The conference papers cover both research areas and the latest trends in the industry. 96 papers from 300+ authors and about 450 participants attended the conference. In all, qualitative papers would be selected to present during the conference. The main topics of the conference have been classified into the following four categories:

- Thermal Engineering
- Energy Science and Engineering
- Design and Development
- Industrial and Production Engineering

The technical advisory committee is pleased to mention that the papers have been received on all these topics. Such a voluminous proceedings is not possible without the generous support received from various quarters. The committee would like to put on record its deep appreciation for the persistent efforts of all reviewers.

We are grateful to all the authors of the papers for having made their contributions to enrich this international conference of RAME-2020.

It is our immense pleasure to express our heartfelt gratitude to Prof. Yogi D. Goswami, University of South Florida, USA; Prof. H.C. LIM, Pusan National University, South Korea; Prof. Afzal Husain, Sultan Qaboos University, Oman; Dr. Nitin Upadhyay, University of Modern Science, Dubai, UAE; Dr. Ashish Shukla, Loughborough University, UK; Dr. Shyam S. Pandey, Kyushu Institute of Technology, Japan; and Dr. Jan Banout, Czech University of Life Science Czech Republic and other colleagues in India and abroad.

Special acknowledgement is made to the support of expert papers and also the generous support received from our distinguished alumnus of DTU, the leading industrialist. We also acknowledge the excellent cooperation received from our colleagues and experts on the review panel, for their painstaking efforts in reviewing the papers.

We duly acknowledge the sponsors with thanks and extend full credit to the publisher (Springer) for accepting the proposal to publish conference proceedings with the book title 'Recent Advances in Mechanical Engineering' under the series title 'Lecture Notes in Mechanical Engineering'.

We sincerely hope that engineering community would find this publication a valuable source of knowledge to profess mechanical engineering in the knowledge age.

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Gandhinagar, India  
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Prashant Kumar Jain



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## About the Editors

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# **Thermal Engineering**

# Experimental Studies of Heat Transfer Under Natural Convection in Heat Pipe Insulated with Vacuum Chamber



Sumit Kumar Rai , Anjaney Pandey , and Alok Chaube 

## Nomenclature

### *Symbol*

$A$	Surface area of HP ( $\text{m}^2$ )
$C_p$	Specific heat ( $\text{J}/(\text{kg K})$ )
$h_{\text{practical}}$	Practical value of CCHT ( $\text{W}/(\text{m}^2 \text{K})$ )
$h_{\text{theoretical}}$	Theoretical value of CCHT ( $\text{W}/(\text{m}^2 \text{K})$ )
$k$	Thermal conductivity ( $\text{W}/(\text{m K})$ )
$Q_{\text{practical}}$	Practical value of RHT (W)
$Q_{\text{theoretical}}$	Theoretical value of RHT (W)

### *Subscript*

CCHT	Coefficient of convective heat transfer
HP	Heat pipe
HPHE	Heat pipe heat exchanger
HPHEVC	Heat pipe heat exchanger insulated with vacuum chamber
RHT	Rate of heat transport

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## 1 Introduction

The heat transfer systems are commonly associated with different types of heat transfer equipment who is working based on sensible heat transfer, latent heat transfer and mixed mode of these two types [1]. The heat transfer system can be designed into single tube and multi-tube type [2], cross flow heat transfer, evaporators and condensers, hollow cylindrical type heat pipe equipment [3], etc. The motivation for making an experimental setup of heat pipe insulated with vacuum chamber is to obtain high exchanger compactness in given surface area having size, position and weight limitations [4, 5]. The heat transfer systems are normally based on the transferring heat from hot fluids to cold fluids with the help of different types of equipment which are used in a variety of engineering applications. The heap pipe system has been divided into three sections, i.e., evaporator, adiabatic and condenser section.[1] The heat transfer inside the heat pipe between hot and cold fluids is by the forced convection or natural convection. The manufacturers normally depend upon the local vendors for procurement of accessories including heat exchangers working under natural or forced convection which may not be optimally designed. Since these heat exchangers are to be acquired in a new design of model with configurations and layout, therefore, even well composition of heat exchangers in a particular configuration is subjected to change in thermal performance [6]. There are a lot of methods to amplify the transferring heat from hot fluids to cold fluids with the help of heat exchanger equipment; one may look for a solution in the given situation. If the area of heat transfer is increased, then heat transfer will be increased, and the other solution is increasing the flow rate of working fluids may be increasing the heat transfer. The first solution takes more space, so it is not helpful for minimum space area and the other solution required more pressure drop between inside section of heat pipe and atmosphere. All these types of studies are limited to forced convection because they need some external forces for transferring the heat by heat pipe in heat exchanger. Therefore, to make heat pipe, heat exchanger under natural convection is required for transferring the heat without any external forces [7] (Fig. 1).

The literature survey reported that the temperature difference between the surface and the working fluids is created natural convections without any external forces. And a model can be developed for transfer the heat through a heat pipe under natural convection conditions [7]. The size and thermo physical properties of material of heat pipe also involve transferring the heat under natural convection conditions [8]. The temperature difference between surface and fluids indicates that good working conditions under natural convection conditions and huge amount of heat transfer through the heat pipe insulated with vacuum chamber. The heat transfer through the natural convection also depends on the properties of fluids, design of heat pipe, position of heat pipe [9] and working environments [3, 9]. These all are critical parameters that affected transferring the heat under natural convective conditions.

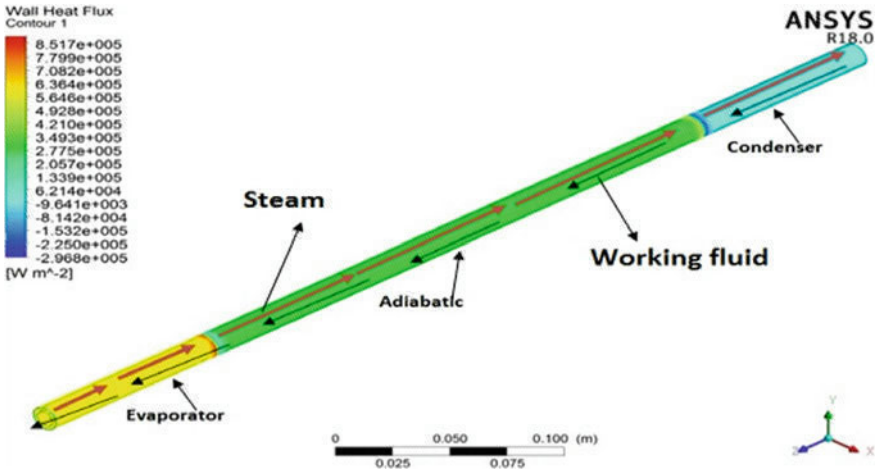


Fig. 1 Heat pipe

## 2 Design Considerations

The present investigation aims at low temperature application, such as cooling of transformer oil, cutting fluids and generated heat from the CPU should be dissipated, and therefore, the operating temperature range of 40–61 °C has been considered.

The availability, cost, properties and operating conditions of fluids are the basic parameters of fluids for selection as working fluids working under natural convection at low temperature range [10]. The viscosities of fluids should be low at liquid and vapor conditions. Based on all above parameters, water, ethanol, methanol and butanol are used as working fluids [11]. The maximum possible heat transfer occurs when water is used as working fluids as compared to the other working fluids.

### 2.1 Development of Analytical Model

An analytical model of heat pipe has been developed to calculating coefficient of heat transfer and heat transfer rate when heat pipe working under natural convection conditions at 40–61 °C inlet heating temperature range [3, 12]. The different heat transfer correlations available in the literature have been used to compute the coefficient of heat transfer, rate of heat transfer across evaporator system of the HPHE.

The analytical considerations for analyzing the HPHE are

1. Laminar flow or turbulent flow regime has been assumed in the evaporator side [2].



2. A temperature range of 40–61 °C is assumed for the heating (hot) fluid in the evaporator section for low temperature applications [3, 12].
3. The thermodynamic properties of heating fluids (water, ethanol, methanol [12] and butanol) and ambient air have been evaluated at the mean temperature of fluids [11].
4. Glass vacuum chamber is used as insulating material surrounding the heat pipe for minimum heat loss to atmosphere [13].

## 2.2 Mathematical Formulations

To determine the CCHT, the HPHE has been modeled as a thermal resistance network [4]. The CCHT have been computed on the internal surface of evaporator. For natural convection condition, the correlations have been taken from a text book of Engineering Thermodynamics written by G.F.C. Rogeks and Y. R. Mayhew. The calculation of CCHT and RHT across the heat pipe under natural convection is described below:

$$\text{Nu} = C(\text{Gr} \times \text{Pr.})^n \quad (1)$$

Natural convection heat transfer from inclined tube from y-axis is computed by the correlations of

$$\text{Nu} = C(\text{Gr} \times \text{Pr} \times \cos \theta)^n \quad (2)$$

where Gr, Pr and Nu represent the value of Grashoff number, Prandtl number [10] and Nusselt number [7, 6], respectively,  $C$  and  $n$  are constant.  $\theta$  is angle of inclination of heat pipe from vertical axis or y-axis [4].

The fluid flow will be laminar flow

$$\text{Nu} = 0.590 \times (\text{Gr} \times \text{Pr} \times \cos \theta)^{0.25}, \quad (3)$$

For  $10^4 < (\text{Gr} \times \text{Pr} \times \cos \theta) < 10^9$ .

The fluid flow will be turbulent flow

$$\text{Nu} = 0.590 \times (\text{Gr} \times \text{Pr} \times \cos \theta)^{1/3}, \quad (4)$$

For  $10^9 < (\text{Gr} \times \text{Pr} \times \cos \theta) < 10^{12}$

$$\text{Nu} = \frac{(\text{ht} \times L1)}{K} \quad (5)$$

where  $h_t$  or  $h_{\text{theoretical}}$  represents the theoretical value of coefficient of convective heat transfer in  $\text{W/m}^2 \text{ } ^\circ\text{C}$ ,  $L$  is the length of heat pipe in m, and  $K$  represents the thermal conductivity of fluids in  $(\text{W/m } ^\circ\text{C})$ .

The heat transport rate by HPHE has been computed by following correlations:

$$Q_{\text{theoretical}} = V.I \tag{6}$$

where  $V$  = Voltage in Volt,  $I$  = Current in ampere.

### 3 Experimentation

The test rig has been designed in a manner such that calculates the value of coefficient of heat transfer and heat transfer rate at different tilt angles under natural convection conditions. A test setup is shown in Fig. 2. The total length of heat pipe is 500 mm, and thickness of heat pipe is 4 mm. The evaporator, adiabatic and condenser lengths are 100 mm, 300 mm and 100 mm, respectively. The evaporator section is insulated with glass chamber when the internal pressure of glass chamber is less than vacuum pressure. The adiabatic section is insulated with glass chamber when the internal pressure of glass chamber is less than vacuum pressure. The condenser is exposed to a chamber made of glass box having length, width and height are 100 mm, 100 mm and 100 mm, respectively, which filled with flowing water at ambient temperature. The condenser removes the heat by natural convection. The working fluids (water, ethanol, methanol and butanol) heated through an electrical heater. Temperature data logger has been used to measure the value of temperature with the help of thermocouples. There are ten thermocouples used for measuring the temperature



Fig. 2 Experimental setup of heat pipe insulated with glass vacuum chamber

from different–different locations of heat pipe. Two thermocouples are mounted with the external surface of evaporator, three thermocouples are mounted with the external surface of adiabatic section, and other four is mounted with the condenser section. One thermocouple is left open in the atmosphere to take a reading of atmospheric temperature. A voltmeter is used to measure the voltage reading in volt, and ammeter is used to take the reading of current in ampere.

The coefficient of convective heat transfer under natural convection was determined with the help of experimental reading. The practical value coefficient of convective heat transfer in  $W/m^2 \text{ } ^\circ C$  was computed as follows:

$$h_p = \frac{Q}{A * dT} \quad (7)$$

The transferring heat by the heat pipe has been calculated with the help of experimental reading. The practical heat transfer rate in  $W/m^2 \text{ } ^\circ C$  was computed as follows:

$$Q_{\text{practical}} = q_1 - q_2 - q_3 \quad (8)$$

$q_1$  = Heat input to the evaporator in W [5]

$$q_1 = \frac{m \cdot cp \cdot \Delta t}{\text{time}} \quad (9)$$

$q_2$  (Heat loss from adiabatic section) [5]

$$q_2 = h \cdot A_a \cdot (T_{\text{adiabatic}} - T_{\text{atm}}) \quad (10)$$

$q_3$  (Heat loss from condenser) [5]

$$q_3 = h \cdot A_c \cdot (T_{\text{condenser}} - T_{\text{atm}}) \quad (11)$$

where  $m$  represents the value of mass flow rate,  $cp$  represents the value of specific heat at given inlet heating temperature, and  $\Delta t$  = temperature difference between walls of heat pipe to atmosphere,  $A_a$  = area of adiabatic section,  $A_c$  = area of condenser section,  $h$  = coefficient of convective heat transfer.

## 4 Results and Discussions

The experimental values of CCHT and RHT of the heat pipe insulated with vacuum chamber under natural convective conditions have been calculated. The analytical values are used to validate the experimental model whether model worked under

natural convection conditions or not. This paper shows the results and comparisons of experimental values of different–different working fluids.

#### ***4.1 CCHT When Water, Ethanol, Methanol and Butanol Used as Working Fluids***

The practical value of CCHT has been calculated with the help of experimental setup for different–different fluids separately. The results of practical value with respect to the inlet temperature of evaporator and tilting angles of heat pipe from vertical axis [11] for water [11, 10], ethanol, methanol [12] and butanol are used as working fluids are shown in Table 1 and Figs. 3, 4, 5, 6 and 7.

Figures 3, 4, 5, 6 and 7 show the results of practical values of CCHT with respect to the inlet heating temperature for water, ethanol, methanol and butanol used as working fluids at different inlet temperature of evaporator.

The value of CCHT is influenced by angle of inclination of heat pipe from vertical axis. It has been observed that the angle of inclination of heat pipe increases from vertical axis  $0^\circ$  to  $15^\circ$ , the coefficient of convective heat transfer increases, and it starts decreasing beyond  $15^\circ$  tilt angles for inlet evaporator temperature  $61^\circ\text{C}$  and methanol, ethanol and butanol used as working fluids.

#### ***4.2 RHT of HPHE for Water, Ethanol, Methanol and Butanol Used as Working Fluids***

The practical value of RHT has been calculated with the help of experimental setup for different–different fluids separately. The results of practical value with respect to the inlet temperature of evaporator and tilting angles of heat pipe from vertical axis [4] for water [11], ethanol, methanol [12] and butanol are used as working fluids are shown in Table 2 and Figs. 8, 9, 10, 11 and 12.

Figures 8, 9, 10, 11 and 12 show the results of practical values of RHT of HPHE with respect to the inlet heating temperature for water, ethanol, methanol and butanol used as working fluids, and the arrangements of heat pipe inclined at different–different tilt angles from vertical axis of HPHE.

The result shows that the HPHE gives the maximum heat transport rate when water is used as a working fluid as compared to ethanol, methanol and butanol. In the case of inclination of heat pipe from its vertical position, it gives good thermal execution when heat pipe is inclined at  $45^\circ$  tilt angles at all the range of inlet temperature of the evaporator and methanol is used as a working fluid.

**Table 1** Coefficient of convective heat transfer for different working fluids under natural convection  
 Coefficient of convective heat transfer for different working fluid under natural convection in  $W/m^2 \text{ } ^\circ C$

		Ethanol																														
Tl	Angle of inclination	0				15				30				45				60														
		$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$													
40		1254.53	1201.03	1201.03	1201.03	1115.23	373.85	40	333.12	323.64	323.64	323.64	310.62	264.84	43	365.13	337.20	337.20	337.20	322.60	291.13	310.62	325.89	349.89	363.27	378.22	434.43	476.84	435.36	336.58		
43		1334.54	1334.97	1273.70	1177.20	1046.33	43	386.70	381.99	386.70	386.70	386.70	344.54	310.62	46	413.68	387.44	387.44	387.44	376.06	325.89	310.62	325.89	349.89	363.27	378.22	434.43	476.84	435.36	336.58		
46		1433.12	1453.80	1388.63	1303.32	1137.87	46	408.46	413.68	408.46	408.46	408.46	376.06	325.89	49	434.82	387.44	387.44	387.44	376.06	325.89	310.62	325.89	349.89	363.27	378.22	434.43	476.84	435.36	336.58		
49		1568.00	1550.37	1473.68	1368.20	1207.53	43	434.82	434.82	434.82	434.82	434.82	386.71	349.89	52	453.55	406.09	406.09	406.09	376.06	325.89	310.62	325.89	349.89	363.27	378.22	434.43	476.84	435.36	336.58		
52		1601.34	1581.72	1555.95	1434.13	1280.43	52	458.20	458.20	458.20	458.20	458.20	406.09	363.27	55	474.40	421.16	421.16	421.16	376.06	325.89	310.62	325.89	349.89	363.27	378.22	434.43	476.84	435.36	336.58		
55		1705.23	1646.66	1659.28	1532.38	1350.23	55	480.97	474.40	480.97	480.97	480.97	406.09	363.27	58	486.39	435.36	435.36	435.36	376.06	325.89	310.62	325.89	349.89	363.27	378.22	434.43	476.84	435.36	336.58		
58		1733.83	1766.17	1632.44	1584.41	1428.78	58	486.39	486.39	486.39	486.39	486.39	406.09	363.27	61	486.39	435.36	435.36	435.36	376.06	325.89	310.62	325.89	349.89	363.27	378.22	434.43	476.84	435.36	336.58		
61		1833.22	1828.98	1768.12	1644.45	1434.67	61	486.39	486.39	486.39	486.39	486.39	406.09	363.27																		
		Methanol																														
Tl	Angle of inclination	0				15				30				45				60														
		$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$	$h_{practical}$		
40		467.95	465.18	441.45	419.21	367.10	40	561.78	557.81	530.87	530.87	495.66	439.90	43	606.43	579.17	538.02	485.28	46	661.44	651.13	635.36	594.38	527.65	43	706.23	700.97	672.71	634.10	553.32	592.19	
43		503.06	507.50	486.92	452.62	387.42	43	611.48	611.48	611.48	611.48	538.02	485.28	46	661.44	651.13	635.36	594.38	527.65	43	706.23	700.97	672.71	634.10	553.32	592.19	675.25	710.76	675.25	592.19		
46		541.24	529.83	497.45	469.53	434.12	46	746.02	746.02	746.02	746.02	634.10	553.32	49	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02
43		552.30	545.95	534.08	495.33	443.35	49	746.02	746.02	746.02	746.02	746.02	746.02	746.02	52	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02	746.02
52		580.93	572.45	551.05	521.78	471.68	52	746.02	746.02	746.02	746.02	746.02	746.02	746.02																		

(continued)

**Table 1** (continued)

		Methanol						Acetone or Butanol																			
TI	Angle of inclination	15			30			45			60			TI	Angle of inclination	15			30			45			60		
		$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$			$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$	$h_{\text{practical}}$
55	600.54	598.17	582.96	540.17	486.92	55	802.72	784.80	755.93	705.35	632.79	58	837.12	825.53	809.01	745.28	663.21	863.11	874.32	838.73	774.85	707.37					
58	643.44	628.93	535.58	564.77	512.02	58	837.12	825.53	809.01	745.28	663.21	SI	849.71	654.00	640.65	587.32	516.34	61	874.32	838.73	774.85	707.37					