



**UNIVERSITI PUTRA MALAYSIA**

**THERMAL DIFFUSIVITY AND QUALITY DETERIORATION INDEX OF  
MALAYSIAN PANGASIU SUTCHI DURING COLD STORAGE**

**KASSIM ALI ABBAS.**

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MALAYSIAN *PANGASIU SUTCHI* DURING COLD STORAGE**

**By**

**KASSIM ALI ABBAS**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia  
In Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

**December 2005**



## DEDICATION

*Especially dedicated to:*

*To my parents, my brothers and sisters*



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment  
of the requirement for the degree of Doctor of Philosophy

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**Chairman: Associate Professor Ir. Megat Mohd Hamdan Megat Ahmad, PhD**

**Faculty : Engineering**

The knowledge on thermal properties of food material to be preserved is considered as one of the basic requirements for conducting heat transfer studies and hence to design proper heat transfer equipments such as refrigerators, freezers and cold storages. The local designers obtain those thermophysical properties data from Europe and America (Ansari et al., 2002).

Experimental measurements have been carried out for the specific heat, mass density, water content, thermal conductivity and thermal diffusivity of Malaysian freshwater *Pangasius Sutchi* fish during precooling process. The mass density was determined by measuring mass and volume of the fish samples and the water content was measured gravimetrically through drying of fish samples in oven. The remaining properties were calculated by empirical formulae, which correlated these properties with water content of fish.

The most significant part in the experimental work was designing and fabrication of an air blast cooling plant of constant 1 °C air stream temperature. This plant has



played the vital role in minimizing the error of the used techniques as well as thermal diffusivity determination.

A non-dimensionalized mathematical model of temperature variation with time and spatial coordinates was made and solved by finite difference method. Factors affecting the solution have been investigated thoroughly to deliver the most accurate and reliable results with the shortest computational time. The calculation procedure has been developed and proposed for heat transfer and simultaneous heat and mass transfer model. The proposed scheme showed more superior results when compared with the results reported in the literature and yielded consistently good agreements with the measurements.

Three approaches of estimating the surface film conductance ( $h$ ) during air-blast cooling process were developed by the present author. Based on the above mathematical model, a comparison between the developed and five of the existing literature approaches was made to identify the best one. A thorough investigation was conducted to establish the most suitable and reliable method of measuring the thermal diffusivity of *Pangasius Sutchi* out of important methods reported in the literature. Due to its superiority, Ansari's method was adapted to calculate the thermal diffusivity, through the transient temperature measurements at five known locations in the fish flesh and at the surface. The estimated  $h$  was used in this method to deliver reliable values of  $\alpha$ .

Four lots of fish samples were preserved in 4 chillers set at 0, 3, 5 and 10°C for 28 days according to normal practice. During the course of cold preservation, the

samples were subjected to three sorts of tests periodically. Firstly, the sensory test which comprises overall acceptance (consumer acceptability acc). Secondly, chemical tests, which included the pH and Thiobarbituric acid (TBA) tests. These tests play the main role in determining the development of rancidity evolution in the fish under present investigations. The last type of test was the thermal diffusivity determination through transient temperature measurements across the muscles orientation, as well as along the muscles orientation.

The above study has revealed that the consumer acceptability (acc), pH and TBA value were found to be strongly dependent upon temperature and time of cold preservation. The results of acc and PH led to yield a graphical solution by which the consumer acceptability and the shelf life of the fish, during cold storage, could be predicted.

TBA was correlated with thermal diffusivity ratio ( $\alpha/\alpha_{fresh}$ ) to develop a tool by which rancidity of fish could be predicted without going through the chemical test, hence, a new quality deterioration index was developed. When the value of  $\alpha/\alpha_{fresh} = 1.0$  indicates absolutely fresh sample, and  $\alpha/\alpha_{fresh} > 1.0$  the lesser the freshness.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia  
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**KEMERESAPAN HABA DAN KESUSUTAN KUALITI BAGI IKAN PATIN  
MALAYSIA SEMASA MENGEKALKAN KESEJUKANNYA.**

Oleh

**KASSIM ALI ABBAS**

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**Pengerusi : Profesor Madya Ir. Megat Mohd Hamdan Megat Ahmad, PhD**

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Pengetahuan tentang sifat termal bahan yang akan diawet merupakan keperluan asas bagi menjalankan kajian pemindahan haba dan bagi mereka bentuk peralatan pemindahan haba yang sesuai seperti peti sejuk dan storan sejuk. Pada masa ini, pereka tempatan meminjam data-data sifat termofizikal ikan air tawar dari Eropah dan Amerika (Ansari et al., 2002).

Dalam kajian ini, pengukuran telah dijalankan bagi menentukan haba tentu, ketumpatan jisim, kandungan air, konduktiviti dan kemeresapan haba bagi ikan *Pangasius Sutchi*, semasa pra-penyejukan. Ketumpatan jisim telah ditentukan dengan mengukur jisim dan isipadu sampel ikan dan kandungan air telah diukur mengikut kaedah gravimetrik melalui pengeringan sampel ikan di dalam ketuhar. Sifat-sifat lain telah dihitung dengan rumusan secara empirikal yang mengaitkan sifat-sifat tersebut dengan kandungan air ikan.

Bahagian terpenting dalam ujikaji ini adalah merekabentuk dan membina logi pendingin bagas udara pada suhu malar, 1°C. Loji ini berfungsi dalam pengiraan kemeresapan haba dan meminimumkan ralat. Satu model matematik tanpa dimensi untuk variasi suhu dengan masa dan koordinat spatial telah dibangunkan dengan kaedah perbezaan terhingga. Faktor mempengaruhi penyelesaian telah dikaji untuk menghasilkan keputusan yang tepat dan boleh harap untuk masa pengkomputeran yang paling pendek. Prosedur pengiraan telah dibangunkan dan dicadangkan untuk model pemindahan haba dan model pemindahan haba dan jisim. Keputusan yang lebih baik telah diperolehi jika dibandingkan dengan keputusan dalam literatur, dan bertepatan dengan keputusan ujikaji.

Tiga kaedah pendekatan bagi menganggar kealiran saput permukaan ( $h$ ) semasa proses penyejukan bagas udara telah dibangunkan. Perbandingan antara lima pendekatan yang dilaporkan oleh penyelidik lain dan tiga lagi yang dibangunkan oleh pengarang telah dijalankan bagi mendapat kaedah yang terbaik. Satu kajian yang menyeluruh telah dijalankan bagi mencari dan membangunkan kaedah yang sesuai bagi mengukur kemeresapan haba bagi ikan air tawar *Pangasius Sutchi*. Keputusan menunjukkan bahawa kaedah Ansari adalah lebih tepat, boleh diharap dan lebih stabil berbanding dengan kaedah lain. Kaedah ini telah diguna pakai bagi mengira kemeresapan haba melalui analisis pemindahan haba transien dengan pengukuran haba pada lima lokasi dalam isi ikan dan pada permukaan ikan. Nilai  $h$  anggaran telah diguna pakai untuk menentukan nilai  $\alpha$ .

Empat kelompok sampel telah diagihkan ke dalam 4 pendingin pada suhu masing-masing 0, 3, 5 dan 10 °C. Kelompok tersebut telah disimpan selama 28 hari mengikut



tabii penstoran lazim. Semasa dalam keadaan beku ini, sampel ikan telah melalui tiga jenis ujian secara berkala. Pertama, ujian deriaan yang meliputi penerimaan pengguna (acc), kedua, ujian kimia yang merangkumi ujian pH dan asid Thiobarbituric (TBA). Ujian ini memainkan peranan yang penting dalam menentukan pembangunan kaedah pengawetan ikan yang dikaji. Ujian terakhir adalah penentuan kemeresapan haba suhu transien (pra - penyejukan) dan juga berdasarkan arah merentang dan selari otot ikan turut dijalankan.

Kajian menunjukkan nilai penerimaan pengguna (acc), pH dan TBA dipengaruhi oleh suhu dan tempoh masa penyejukan. Keputusan penerimaan pengguna dan pH secara graf untuk digunakan dalam membuat jangkaan keatas tahap kesegaran ikan sepanjang tempoh storan sejuk.

TBA dikolerasikan dengan sifat termal ( $\alpha/\alpha_{\text{segar}}$ ) digunakan untuk membangunkan satu kaedah untuk menentukan tahap pengawetan ikan tanpa melalui ujian kimia dan seterusnya indeks tahap kesegaran ikan secara berangka menerusi suhu pengawetan telah dibangunkan. Nilai bagi pecahan  $\alpha/\alpha_{\text{segar}} = 1.0$  bermaksud sampel ikan adalah segar sepenuhnya, dan apabila nilai  $\alpha/\alpha_{\text{segar}} > 1.0$  kesegaran ikan akan berkurangan.

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## NOMENCLATURE

A	Area
acc	Sensory score
Bi	Biot number
cp	Specific heat capacity on mass basis
D	Day
e	Error percent
F	Fat fraction
Fo	Fourier number
h	Surface film conductance (coefficient of heat transfer)
$h_c$	Convection part of coefficient of heat transfer
$h_d$	Mass diffusivity coefficient
$h_e$	Effective (total) coefficient of heat transfer
$h_{fg}$	Latent heat of vaporization
$h_{me}$	Part of coefficient of heat transfer due to moisture evaporation
$h_r$	Radiation part of coefficient of heat transfer
k	Coefficient of thermal conductivity
L	Latent heat of fusion on volume basis
m	Mass
$m_s$	Mass of sample
$m_w$	Mass of water
n	Number of equal divisions of the characteristic length
Nu	Nusselt number
p	Protein content fraction



P	Vapour pressure of unsaturated air
$P_{\text{atm}}$	Atmospheric pressure
pH	Acidity of fish sample
pHo	Acidity of fresh fish sample
Pr	Prandtl number
$P_s$	Vapour pressure of the wetted surface
Q	Heat energy
$q_i$	Rate of heat flux
$q$	Rate of heat generation of the sample
R	Relative spoilage rate
Re	Reynolds number
$R_f$	Final resistance of the thermistor
RH	Relative humidity
$r_o$	Radius of cylinder or sphere
S	Slope of the line, temperature versus log
Sc	Sensitivity coefficient
SL	Shelf life in days
t	Time
TBA	Rancidity index
$T_{\text{db}}$	Dry bulb temperature of the cooling air
$T_e$	Equilibrium temperature of the mixture
$T_{\text{wb}}$	Wet bulb temperature of the cooling air
U	Non-dimensional temperature
v	Volume
W	Percent water content on weight basis

$x$	Space co-ordinate
$X$	Non-dimensional space co-ordinate
$X'_a$	Ash content, decimal
$X'_c$	Carbohydrate content, decimal
$X'_f$	Fat content, decimal
$X'_p$	Protein content, decimal
$x_0$	Characteristic length (half thickness slab or radius for cylinder and spher
$X_w$	Mass fraction of water

### **GREEK LETTERS**

$\alpha$	Coefficient of thermal diffusivity
$\rho$	Mass density
$\theta$	Weighing factor in the implicit-explicit Scheme
$\phi_c$	Temperature difference between the object center and the coolant
$\phi_s$	Temperature difference between the object surface and the coolant

### **SUBSCRIPTS AND SUPERSSCRIPTS**

$+$	Dimensionless
$1$	First test
$2$	Second test
ave	Average
cm	Cooling medium
db	Dry bulb temperature
e	End
f	frozen