VISUALISASI DISTRIBUSI SUHU KEADAAN *TRANSIENT* DAN *STEADY STATE* PADA BAHAN MENGGUNAKAN METODE BEDA HINGGA

(Skripsi)

Oleh

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JURUSAN FISIKA
FAKULTAS MATEMATIKA DAN ILMU PENGETAHUAN ALAM
UNIVERSITAS LAMPUNG

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FAHAD ALMAFAKIR

Skripsi

Sebagai Salah Satu Syarat untuk Memperoleh Gelar
SARJANA SAINS

Pada

Jurusan Fisika
Fakultas Matematika dan Ilmu Pengetahuan Alam

JURUSAN FISIKA
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Judul	:	Visualisasi Distribusi Suhu Keadaan *Transient* dan *Steady State* pada Bahan Menggunakan Metode Beda Hingga
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ABSTRAK

VISUALISASI DISTRIBUSI SUHU KEADAAN *TRANSIENT* DAN *STEADY STATE* PADA BAHAN MENGGUNAKAN METODE BEDA HINGGA

Oleh

Fahad Almafakir

Telah dilakukan penelitian visualisasi distribusi suhu keadaan *transient* dan *steady state* pada bahan menggunakan metode beda hingga dalam berbagai dimensi. Satu dimensi bahan homogen yang diselesaikan dengan metode Crank-Nicolson dan *multilayer* keadaan *transient* dengan metode eksplisit, dua dimensi bahan homogen keadaan *transient* diselesaikan dengan metode eksplisit dan bahan sembarang keadaan *steady state* dengan metode iterasi *Succesive Over Relaxation* (SOR) dan tiga dimensi bahan homogen keadaan *transient* yang dieselesaikan dengan metode eksplisit, ketiganya menggunakan bahan Aluminium (Al) dan Perak (Ag) dengan batas *Dirichlet*. Keadaan *transient* menggunakan persamaan difusi dan keadaan *steady state* adalah persamaan Laplace. Penelitian ini menunjukkan bahwa distribusi suhu pada bahan Ag lebih cepat dibandingkan dengan bahan Al dan bahan *multilayer* Al-Ag-Al lebih cepat dibandingkan Ag-Al-Ag. Perbedaan distribusi suhu ini disebabkan karena difusivitas bahan Ag lebih besar dibandingkan bahan Al..

Kata kunci. *Transient*, *steady state*, homogen, *multilayer*, *Dirichlet.*

ABSTRACT

VISUALIZATION OF TEMPERATURE DISTRIBUTION TRANSIENT AND STEADY STATE ON THE MATERIALS USING FINITE DIFFERENCE METHODS

By

Fahad Almafakir

Visualization of temperature distribution transient and steady state on the material using finite difference methods in various dimensions had been reasearched. One dimensional homogeneous materials solved by methods Crank-Nicolson and multilayer state of transient with explicit methods, two dimensional homogeneous materials transient state solved by explicit methods and random materials steady state with the iteration method Successive Over Relaxation (SOR) and three dimensional homogeneous material transient state solved by explicit methods, the trio material uses Aluminium (Al) and silver (Ag) with Dirichlet boundary. Transient state using diffusion equation and the steady state is the Laplace equation. This study shows that the temperature distribution of the Ag material faster than Al materials and multilayer materials Al-Ag-Al faster than Ag-Al-Ag. The difference is due to the temperature distribution of the material diffusivity of Ag greater than Al materials.

Key words. *Transient, steady state, homogeneus, multilayer, Dirichlet*

KATA PENGANTAR

Puji syukur atas kehadirat Allah SWT yang telah melimpahkan rahmat dan hidayah-Nya sehingga penulis dapat menyelesaikan skripsi yang berjudul **"Visualisasi Distribusi Suhu Keadaan *Transient* dan *Steady State* pada Bahan Menggunakan Metode Beda Hingga"**sebagai syarat untuk memperoleh gelar Sarjana Sains (S.Si) di bidang keahlian Instrumentasi Jurusan Fisika Fakultas Matematika dan Ilmu Pengetahuan Alam Universitas Lampung, shalawat dan salam senantiasa tercurahkan kepada Rasulullah SAW, keluarga, sahabat dan pengikutnya yang senantiasa istiqomah.

Penulis menyadari bahwa skripsi ini masih banyak terdapat kekurangan. Oleh karena itu, penulis dengan terbuka menerima saran dan kritik yang bersifat membangun demi kesempurnaan skripsi ini. Semoga skripsi ini bermanfaat bagi kita semua. *Aamiin*.

Bandar Lampung, 13 Januari 2017

Penulis

SANWACANA

Alhamdulillahirabbil'alamiin, penulis menyadari bahwa skripsi ini dapat terselesaikan dengan baik berkat dorongan, bantuan dan motivasi dari berbagai pihak, oleh karena itu pada kesemapatan ini penulis ingin mengucapkan terimakasih kepada:

1. Bapak Prof. Dr. Warsito, D.E.A sebagai pembimbing I sekaligus Dekan FMIPA Unila.
2. Ibu Sri Wahyu Suciyati, S.Si., M.Si sebagai pembimbing II.
3. Bapak Arif Surtono, S.Si., M.Si, M.Eng sebagai penguji sekaligus Ketua Jurusan Fisika FMIPA.
4. Bapak Prof. Drs. Posman Manurung, M.Si sebagai pembimbing akademik.
5. Saudara dan sahabat: Henry Cahyono, Irham Hidayat, Ahmad Husnan, Syarifudin, Wahyu Indarto, Saifudin, Bastian Adam keluarga besar HIMAFI, DPM FMIPA dan ROIS FMIPA, kakak dan adik tingkat 2009, 2010, 2012, 2013 dan seluruh saudara dan sahabat yang tidak dapat disebutkan yang menyemangati dan membantu untuk menyelesaikan skripsi ini.

Bandar Lampung, 10 Februari 2017

Penulis

RIWAYAT HIDUP

Penulis bernama lengkap Fahad Almafakir, dilahirkan di Gunung Sugih II, 27 November 1992, anak ke enam dari delapan bersaudara pasangan Bapak Sareh Samin dan Ibu Suparmi. Penulis menempuh pendidikan dasar di SDN 1 Pesawaran dan diselesaikan tahun 2004. Pendidikan Menengah Pertama diselesaikan di MTs MA Tempel Rejo tahun 2007. Pendidikan Menengah Atas di MAN Pesawaran yang diselesaikan pada tahun 2010. Kemudian pada tahun 2011 penulis terdaftar sebagai mahasiswa di Universitas Lampung melalui jalur Seleksi Bersama Masuk Perguruan Tinggi Negeri (SBMPTN) Tertulis pada Jurusan Fisika FMIPA dan memilih konsentrasi KBK Fisika Instrumentasi.

Selama menempuh pendidikan penulis pernah menjadi asisten Praktikum Fisika Dasar I dan II pada tahun 2013 dan praktikum Fisika Komputasi pada tahun 2014. Penulis aktif pada kegiatan organisasi ROIS FMIPA sebagai Kepala Biro Akademik periode 2012-2013, HIMAFI periode 2013-2014 sebagai ketua umum dan DPM FMIPA periode 2014-2015 sebagai ketua. Penulis juga mengikuti Praktik Kerja Lapangan pada tahun 2014 di PLTD Teluk Betung dengan judul "Sistem Proteksi Generator Siemens 1DK 5417-DE 10-Z Sebagai Pembangkit Listrik Tenaga Diesel 20 KV pada PT. PLN (Persero) Sektor Bandar Lampung PLTD Teluk Betung".

PERNYATAAN

Dengan ini Saya menyatakan bahwa dalam skripsi ini tidak terdapat karya yang pernah dilakukan orang lain, dan sepanjang pengetahuan Saya juga tidak terdapat karya atau pendapat yang ditulis atau diterbitkan oleh orang lain, kecuali yang secara tertulis diacu dalam naskah ini sebagaimana disebutkan dalam daftar pustaka, selain itu Saya menyatakan pula bahwa skripsi ini dibuat oleh Saya sendiri.

Apabila pernyataan ini tidak benar maka saya bersedia dikenakan sanksi sesuai dengan hukum yang berlaku.

Bandar Lampung, 14 Februari 2017

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Bismillahirrahmaanirrahim

Dengan ini Saya persembahkan karya ini untuk:

Kedua orang tua tercinta **Abah Sareh Samin** dan **Mamak Suparmi**

Kang Nurkholis, Kang Ahmad Bahromi, Kang Aziz Munazar, Teh Fida Alina,

Kang Mahfuz Hudori, Masturoh dan Syaiful Rahman

(terima kasih atas do'a dan pengorbanan yang tiada henti).

Serta seorang wanita *shalihah* yang kelak akan menjadi pendamping

dinullah dan insyaAllah dijaga oleh Allah SWT.

MOTO

"*yang patah tumbuh yang hilang berganti*"

(Fahad Almafakir)

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III. METODE PENELITIAN

IV. HASIL DAN PEMBAHASAN

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BAB I

PENDAHULUAN

A. Latar Belakang

Visualisasi komputasi merupakan metode yang digunakan untuk menggambarkan fenomena-fenomena fisika secara visual, dalam memvisualisasi fenomena-fenomena fisika dibutuhkan suatu model berbentuk persamaan matematika yang selanjutnya dapat memecahkan permasalahan yang dihadapi, dengan memperhatikan syarat batas dan asumsi-asumsi untuk penyederhanaan model.

Perpindahan panas (*heat transfer*) merupakan fenomena fisis yang terkait perpindahan energi yang terjadi karena adanya perbedaan suhu diantara material (Long dan Sayma, 2009). Energi ini tidak dapat diukur atau diamati secara langsung tetapi arah perpindahan distribusi suhu dan pengaruhnya dapat diamati dan diukur.

Persamaan matematika yang digunakan untuk pemodelan distribusi suhu adalah Persamaan Diferensial Parsial (PDP). PDP ini merupakan bagian dari persamaan diferensial yang melibatkan lebih dari satu variabel independen (Sianipar, 2013). PDP yang berkaitan dengan distribusi suhu adalah PDP Parabolik yang merupakan asosiasi dari persamaan difusi. Metode pemodelan yang digunakan untuk menyelesaikan PDP Parabolik ini antara lain dengan pendekatan metode beda hingga langsung dan tidak langsung. Metode langsung bekerja dalam sejumlah langkah yang dapat ditebak dan akan secara langsung mengakhiri operasi yang ada dengan sebuah solusi eksak yang terdiri dari beberapa skema pendekatan yaitu skema eksplisit, implisit dan Crank-Nicolson (Saad, 2003). Metode tidak langsung merupakan metode iterasi untuk menentukan solusi PDP, yaitu metode *Succesive Over Relaxation* (SOR).

Penelitian tentang distribusi suhu ini sudah dilakukan oleh peneliti-peneliti sebelumnya diantaranya adalah Aminin (2008) yaitu menghitung perambatan difusi panas pada kawat satu dimensi yang diselesaikan dengan menggunakan metode beda hingga dengan skema *Forward Time Centered Space* (FTCS), kemudian Wahyu Rizal (2010) merancang dan membuat sistem akuisisi data untuk uji tak rusak bahan berdasarkan pemindaian panas logam berbentuk plat dengan memberikan sumber panas elemen solder, kemudian penelitian Sailah (2010) menghitung distribusi temperatur satu dimensi dengan menggunakan metode beda hingga skema Crank-Nicolson tanpa visualisasi grafik. Kemudian peneliti selanjutnya adalah Supardiyono (2011) yaitu menganalisis distribusi suhu pada setiap titik pada pelat dua dimensi dalam keadaan *steady state* menggunakan metode beda hingga.

Berdasarkan penelitian-penelitian sebelumnya, pertama peneliti tertarik untuk memvisualisasikan distribusi suhu pada bahan homogen dan *multilayer* satu dimensi masing-masing menggunakan metode Crank-Nicolson dan Eksplisit dalam keadaan *transient*, distribusi suhu satu dimensi merupakan bentuk distribusi panas pada kawat yang diberikan panas pada bagian tengah kawat. Kedua, bahan homogen dan sembarang dua dimensi keduanya masing-masing meggunkan metode Eksplisit keadaan *transient* dan SOR keadaan *steady state*, distribusi suhu dua dimensi ini merupakan bahan berbentuk plat dua dimensi keadaan ideal dan berbentuk cacat. Ketiga, bahan homogen tiga dimensi keadaan *transient*, distribusi suhu tiga dimensi merupakan distribusi pada bahan berbentuk kubus yang diberikan panas di tengah bahan. Keaadaan distribusi suhu yang diberlakukan dalam penelitian terbagi menjadi keadaan *transient* dan *steady state*. Keadaan *transient* memerlukan waktu dan difusivitas bahan untuk *step* distribusi suhu, sedangkan *steady state* tidak memerlukan waktu dan difusivitas bahan.

Untuk membantu menyelesaikan distribusi suhu pada bahan peniliti menggunakan *software* Matlab 8.1. Matlab dalam tingkatan versinya mampu melakukan komputasi matematik, menganalisis data, mengembangkan algoritma, melakukan simulasi dan pemodelan serta menghasilkan tampilan grafik dan antarmuka grafikal (Sianipar, 2013).

B. Rumusan Masalah

Dari uraian latar belakang di atas maka dapat dibuat rumusan masalah sebagai berikut:

1. bagaimana menyelesaikan PDP satu dimensi bahan homogen dan *multilayer* keadaan *transient*, dua dimensi bahan homogen keadaan

transient dan bahan sembarang keadaan *steady state* dan tiga dimensi bahan homogen keadaan *transient*; dan

2. bagaimana visualisasi distribusi suhu satu dimensi bahan homogen dan *multilayer* keadaan *transient*, dua dimensi bahan homogen keadaan *transient* dan bahan sembarang keadaan *steady state* dan tiga dimensi bahan homogen keadaan *transient* dengan bantuan *software* Matlab 8.1.

C. Tujuan Penelitian

Tujuan yang ingin dicapai pada penelitian ini adalah sebagai berikut:

1. diperoleh penyelesaian PDP satu dimensi bahan homogen dan *multilayer* keadaan *transient*, dua dimensi bahan homogen keadaan *transient* dan bahan sembarang keadaan *steady state* dan tiga dimensi bahan homogen keadaan *transient*; dan
2. memvisualisasi distribusi suhu satu dimensi bahan homogen dan *multilayer* keadaan *transient*, dua dimensi bahan homogen keadaan *transient* dan bahan sembarang keadaan *steady state* dan tiga dimensi bahan homogen keadaan *transient* dengan bantuan *software* Matlab 8.1.

D. Batasan Masalah

Batasan masalah penelitian ini meliputi:

1. penerapan PDP yang digunakan untuk distribusi suhu berlaku pada bahan homogen isotropik;

2. bahan keadaan homogen merupakan bentuk bahan ideal, tidak memiliki cacat.
3. distribusi suhu pada bahan yang berlangsung dalam kondisi *transient* tidak ada energi tergenerasi $\dot{E}_g$ dalam bahan;
4. tidak ada reaksi luar pada bahan ketika belangsung distribusi suhu;
5. dimensi distribusi suhu yang divisualisaikan yaitu satu dimensi bahan homogen dan *multilayer* keadaan *transient*, dua dimensi bahan homogen keadaan *transient* dan bahan sembarang keadaan *steady state* dan tiga dimensi bahan homogen keadaan *transient*;
6. visualisasi distribusi bahan *multilayer* dilakukan dengan menggunakan tiga lapisan bahan dengan sifat konduktifitas α bahan yang berbeda;
7. bahan yang digunakan pada visualisai keadaan *transient* adalah Aluminium dan Perak; dan
8. *software* yang digunakan pada penilitian adalah Matlab 8.1.

E. Manfaat Penelitian

Manfaat yang diharapkan dari penelitian ini adalah sebagai berikut:

1. diperolehnya simulator distribusi suhu satu dimensi bahan homogen dan *multilayer* keadaan *transient*, dua dimensi bahan homogen keadaan *transient* dan bahan sembarang keadaan *steady state* dan tiga dimensi bahan homogen keadaan *transient*;
2. diperolehnya visualisasi distribusi suhu satu dimensi bahan homogen dan *multilayer* keadaan *transient*, dua dimensi bahan homogen keadaan

transient dan bahan sembarang keadaan *steady state* dan tiga dimensi bahan homogen keadaan *transient*;dan

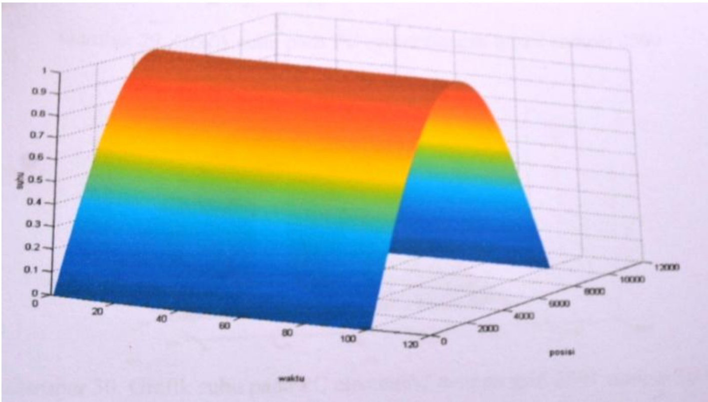
3. sebagai referensi bagi penelitian selanjutnya.

BAB II

TINJAUAN PUSTAKA

A. Penelitian Terdahulu

Penelitian tentang distribusi suhu ini dilakukan sebelumnya oleh Aminin (2008) yaitu menghitung perambatan difusi panas pada kawat satu dimensi yang diselesaikan dengan metode beda hingga dengan skema *Forward Time Centered Space* (FTCS). Hasil penelitiannya berupa perhitungan perambatan difusi panas kawat satu dimensi dengan merancang dan merealisasikan perhitungannya pada aplikasi sistem paralel multikomputer. Realisasi sistem paralel multikomputer ini dirancang untuk mendapatkan proses komputasi yang lebih cepat dengan mengikat beberapa komputer menjadi suatu *virtual machine.* Mesin paralel multikomputer ini dibentuk oleh *software* MPICH yang mampu mengambil *resource* PC dalam jaringan. Sehingga diperoleh sumber daya komputasi yang lebih besar. Perhitungan komputasi sistem paralel ini kemudian di kombinasikan antara 2 PC dan 4 PC. Hasil yang diperoleh pada penelitian ini diketahui *speed up* 1,93 dan efesiensi kinerja sebesar 48% pada kombinasi 2 PC dan *speed up* 2,58 dan efesiensi kinerja sebesar 65% pada kombinasi 4 PC sedangkan hasil penelitian grafik perambatan difusi panas oleh satu PC dilihat pada Gambar 1.

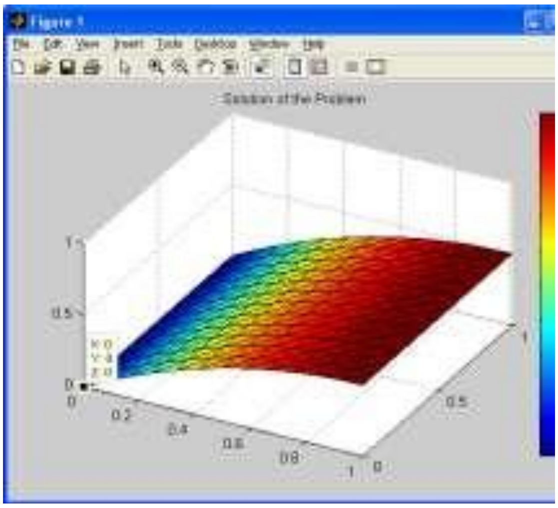


Gambar 1. Grafik suhu terhadap $\Delta t = 0{,}001$ dengan *grid* sebanyak 10.000 (sumber: Aminin, 2008).

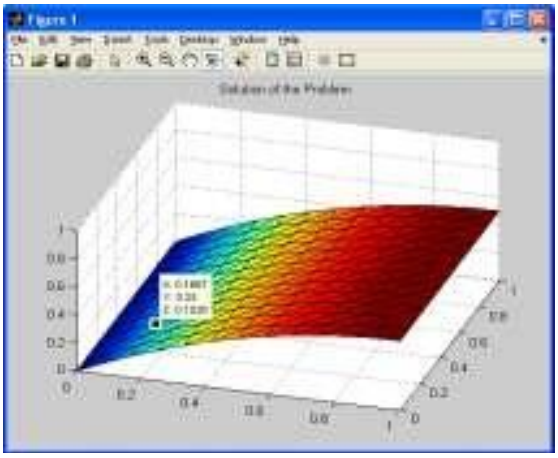
Penelitian selanjutnya dilakukan oleh Rizal (2010) dengan merancang dan membuat sistem akuisisi data untuk uji tak rusak bahan berdasarkan pemindaian panas logam dengan memberikan sumber panas elemen solder. Uji tak rusak bahan logam ini digunakan pada plat logam sebagai pemindai digunakan mikrokontroler ATMega 16 untuk mengakuisisi data dari sensor suhu LM35DZ dan mengatur perputaran motor DC untuk menggerakkan lengan pemindai. Sensor digunakan untuk memberikan data besarnya panas dipermukaan logam akibat diberi rangsangan panas kemudian hasil pemindaian digunakan jalur komunikasi data *Universal Serial Bus* (USB) sebagai *interfacing* komputer. Kemudian untuk menampilkan data pada komputer mengunakan *software* Visual Basic 6.0. Pemindai yang diteliti memiliki resolusi termik untuk sensor 1 sebesar $0{,}009\, mV/C$ dan untuk sensor 2 sebesar $0{,}008\, mV/C$. Hasil yang didapat pada penelitian ini diperoleh bahwa logam memiliki sifat sebagai penghantar panas dan nilai homogenitas konduktifitas panas ditunjukkan dengan adanya perbedaan suhu yang tidak mencolok jika dua buah titik pengukuran diberi suatu rangsangan panas.

Penelitian lainnya dilakukan oleh Sailah (2010) untuk menentukan distribusi temperatur menggunakan metode Crank-Nicholson. Pada penelitian ini, peneliti hanya menghitung distribusi temperatur yang melibatkan persamaan diferensial dengan model matematis perambatan panas persamaan parabolik satu dimensi. Selain itu, digunakan metode Crank-Nicholson dengan penyelesaian Gauss-Seidel untuk menghitung distribusi temperatur. Hasil penelitian menunjukkan bahwa terjadi perambatan panas menuju bagian tengah benda karena ujung-ujung benda dipertahankan bertemperatur 0 ^{0}C dan temperatur menurun sebagai fungsi waktu karena terjadi perpindahan panas ke bagian yang lain. Namun, penelitian ini memiliki beberapa kekurangan diantaranya hanya menghitung nilai distribusi suhu dan tidak menampilkan dalam bentuk grafik dan menggunakan persamaan distribusi suhu satu dimensi. Hasil perhitungan ini dapat dilihat pada Tabel 1 (lampiran).

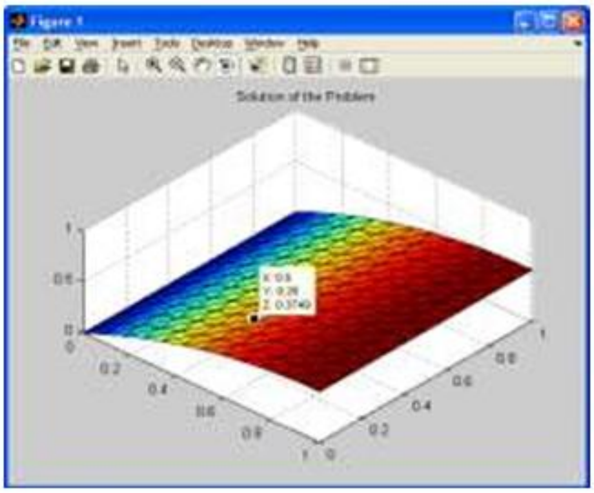
Penelitian distribusi suhu juga pernah dilakukan oleh Supardiyono (2011) mengenai analisis distribusi suhu setiap titik pada pelat dua dimensi menggunakan metode beda hingga. Penelitian tersebut mengkomputasikan distribusi suhu menggunakan persamaan Laplace dua dimensi dengan metode beda hingga menggunakan *software* Matlab 7.0. Hasil penelitian ditunjukkan bahwa visualisasi berupa grafik pada program Matlab untuk menyelesaikan persamaan Laplace dua dimensi terdapat kecocokan dengan grafik pada teori tentang aliran suhu dan berdasarkan grafik yang diperoleh hasil numerik dengan analitik saling berhimpit atau mendekati yang dapat dilihat dari selisih atau tingkat eror keduanya yang tidak terlalu jauh. Pada penelitian tersebut diketahui bahwa peneliti menggunakan persamaan Laplace dua dimensi untuk menentukan distribusi suhu benda pada tiap titik dalam bidang persegi dua dimensi. Hasil distribusi suhu dari penelitian Supardiyono (2011) dapat dilihat pada gambar 2, 3, 4 dan 5.



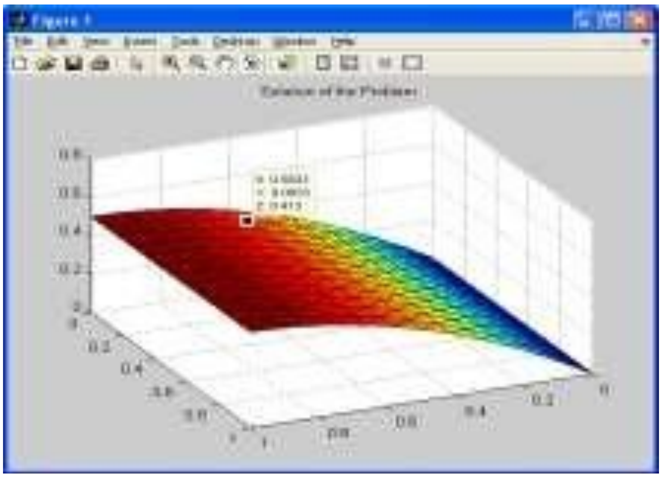
Gambar 2. Distribusi Suhu Persamaan Laplace dua dimensi dengan Nilai $x = 0,\ y = 0$ dan $T = 0$ (sumber: Supardiyono, 2011).



Gambar 3. Distribusi Suhu Persamaan Laplace dua dimensi dengan nilai $x = 0{,}1667,\ y = 0{,}25$ dan $T = 0{,}1528$ (sumber: Supardiyono, 2011).



Gambar 4. Distribusi Suhu Persamaan Laplace dua dimensi dengan nilai $x = 0{,}5$, $y = 0{,}25$ dan $T = 0{,}3749$ (sumber: Supardiyono, 2011).



Gambar 5. Distribusi Suhu Persamaan Laplace dua dimensi dengan nilai $x = 0{,}5833$, $y = 0{,}0833$ dan $T = 0{,}5833$ (sumber: Supardiyono, 2011).

B. Perbedaan dengan Penelitian Sebelumnya

Pada penelitian ini penulis melakukan visualisasi distribusi suhu satu dimensi bahan homogen dan *multilayer* keadaan *transient*, dua dimensi bahan homogen keadaan *transient* dan bahan sembarang keadaan *steady state* dan tiga dimensi bahan homogen keadaan *transient* dengan bantuan *software* Matlab 8.1.

C. Teori Dasar

1. Perpindahan Suhu

Panas mengalir dari benda bertemperatur lebih tinggi ke benda bertemperatur lebih rendah. Laju perpindahan panas yang melewati benda padat sebanding dengan gradien temperatur atau benda temperatur persatuan panjang. Mekanisme perpindahan panas dapat terjadi secara konduksi, konveksi dan radiasi (Holman, 1997).

a. Konduksi

Perpindahan panas secara konduksi adalah proses perpindahan panas dari daerah bersuhu tinggi ke daerah bersuhu rendah dalam suatu medium (padat, cair atau gas) atau antara medium-medium yang berlainan yang bersinggungan secara langsung (Holman, 1997).

Perpindahan panas secara konduksi dinyatakan dengan Persamaan (1),

$$q = -kA\frac{dT}{dx} \tag{1}$$

dengan

q = perpindahan panas (w)

A = luas penampang dimana panas mengalir (m^2)

$\frac{dT}{dx}$ = gradien suhu pada penampang atau laju perubahan suhu T terhadap jarak dalam aliran panas x

k = perpindahan panas $(w/m\ {}^{0}C)$

(Long dan Seyma, 2009).

b. Konveksi

Perpindahan panas secara konveksi adalah perpindahan energi dengan gabungan dari konduksi panas, penyimpanan energi dan gerakan mencampur. Proses terjadi pada permukaan padat lebih panas atau dingin terhadap cairan atau gas lebih dingin atau panas (Holman, 1997).

Perpindahan panas secara konveksi dinyatakan dengan Persamaan (2).

$$q = hA(\Delta T) \tag{2}$$

dengan

q = perpindahan panas (w)

A = luas penampang dimana panas mengalir (m^2)

h = konstanta perpindahan panas konveksi $(w/m^2$ °C)

ΔT = perubahan atau perbedaan suhu (°C)

(Long dan Seyma, 2009).

c. Radiasi

Perpindahan kalor secara pancaran atau radiasi adalah perpindahan kalor suatu benda ke benda lain melalui gelombang elektromagnetik tanpa medium perantara dan apabila pancaran kalor menimpa suatu bidang maka sebagaian besar dari kalor pancaran yang diterima benda tersebut akan dipancarkan kembali (*re-radiated*), dipantulkan (*reflected*) dan sebagian kalor akan diserap (Halauddin, 2006).

Perpindahan panas secara radiasi dinyatakan dengan Persamaan (3).

$$q = -\delta A(T_1^4 - T_2^4) \tag{3}$$

dengan

q = perpindahan panas (w)

A = luas penampang dimana panas mengalir (m^2)

δ = konstanta Stefan-Boltzman $(5{,}669 \times 10^2 w/m^2 k^4)$

T = temperatur $(°C)$

(Long dan Seyma, 2009).

2. Konduktivitas Termal k

Konduktivitas adalah sifat bahan yang menunjukkan berapa cepat bahan tersebut dapat menghantarkan arus panas konduksi dan adapaun k adalah panas yang mengalir tiap satuan waktu melalui tebal dinding $1\ ft$ yang luasnya $1\ ft^2$ apabila diberikan beda suhu 1° (Holman, 1997). Untuk melihat konduktivitas termal berbagai macam bahan pada $300\ K$ dapat dilihat pada Tabel 2.

Tabel 2. Konduktivitas termal k pada $300\ K$.

No.	Bahan	$\frac{W}{m\ K}$
1.	Aluminium Murni	237
2.	Berilium	200
3.	Bismut	7,86
4.	Boron	27,0
5.	Cadmium	96,8
6.	Chromium	93,7
7.	Cobalt	99,2
8	Germanium	59,9
9.	Emas	317
10.	Iridium	147
11.	Besi Murni	80,2
12.	Baja	15,1
13.	Magnesium	156
14.	Nikel Murni	90,7
15.	Platina Murni	71,6
16.	Perak	429
17.	Tantalum	57,3

(sumber: Incropera dan Dewitt, 2011).

3. Panas Spesifik c_p

Panas spesifik c_p merupakan jumlah panas yang diperlukan untuk menaikkan suhu 1 kg bahan sebesar 1 ℃. Panas spesifik sangat diperlukan untuk perhitungan proses-proses pemanasan atau pendinginan bahan. Untuk melihat panas spesifik bahan c_p dapat dilihat pada Tabel 3.

Tabel 3. Panas Spesifik c_p.

No.	Bahan	$\frac{J}{kg\ K}$
1.	Aluminium Murni	903
2.	Berilium	1.825
3.	Bismut	122
4.	Boron	1.107

5.	Cadmium	231
6.	Chromium	449
7.	Cobalt	421
8	Germanium	322
9.	Emas	129
10.	Iridium	130
11.	Besi Murni	447
12.	Baja	480
13.	Magnesium	1.024
14.	Nikel Murni	444
15.	Platina Murni	133
16.	Perak	235
17.	Tantalum	140

(sumber: Incropera dan Dewitt, 2011).

4. Massa Jenis ρ

Massa jenis atau *density* suatu zat adalah kuantitas konsentrasi zat dan dinyatakan dalam massa persatuan volume. Nilai massa jenis suatu zat dipengaruhi oleh temperatur. Semakin tinggi temperatur, kerapatan suatu zat semakin rendah karena molekul-molekul yang saling berikatan akan terlepas (Holman, 1997). Massa jenis ρ berbagai bahan dapat dilihat pada Tabel 4.

Tabel 4. Massa jenis ρ.

No	Bahan	$\frac{kg}{m^3}$
1.	Aluminium Murni	2.702
2.	Berilium	1.850
3.	Bismut	9.780
4.	Boron	2.500
5.	Cadmium	8.650
6.	Chromium	7.160
7.	Cobalt	8.862
8	Germanium	5.360
9.	Emas	19.300
10.	Iridium	22.500
11.	Besi Murni	7.780

12.	Baja	8.055
13.	Magnesium	1.740
14.	Nikel Murni	8.900
15.	Platina Murni	21.450
16.	Perak	10.500
17.	Tantalum	16.600

(sumber: Incropera dan Dewitt, 2011).

5. Persamaan Diferensial Parsial (PDP)

Dalam Strauss (1992) persamaan diferensial parsial adalah persamaan yang memuat hubungan beberapa variabel bebas, satu variabel tak bebas dan turunan parsial dari variabel tak bebas tersebut.

Persamaan diferensial parsial memiliki bentuk umum:

$$A\emptyset_{xx} + B\emptyset_{xy} + C\emptyset_{yy} = f(x, y, \emptyset, \emptyset_x, \emptyset_y) \tag{4}$$

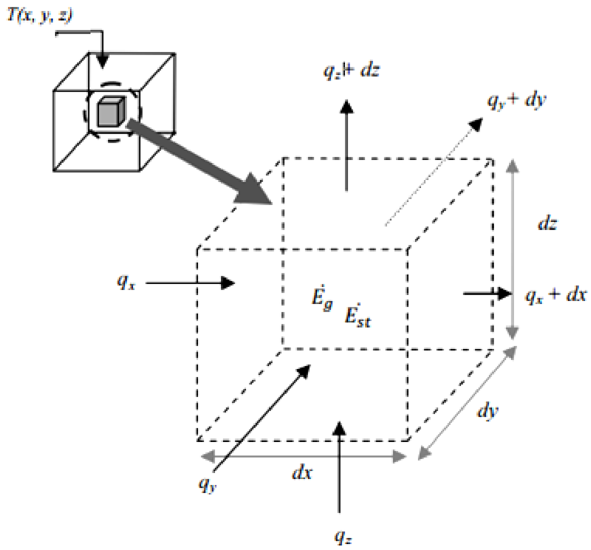
dimana A, B dan C adalah konstanta yang disebut dengan quasilinear. Terdapat tiga tipe dari persamaan quasilinear yaitu:

a. jika $B^2 - 4AC < 0$, persamaan disebut dengan persamaan elips;
b. jika $B^2 - 4AC = 0$, persamaan disebut dengan persamaan parabolik; dan
c. jika $B^2 - 4AC > 0$, persamaan disebut dengan persamaan hiperbolik (Suarga, 2007).

6. Persamaan Difusi

Salah satu cara untuk menentukan distribusi temperatur menurut Incropera dan Dewitt (2011) adalah melalui pendekatan metodologi dengan menerapkan persyaratan kekekalan energi yang meliputi beberapa langkah, yaitu menetapkan daerah *differential control volume*, mengidentifikasi proses transfer energi dan menyatakan persamaan laju difusi yang sesuai. Sehingga diperoleh hasil berupa persamaan diferensial yang merupakan solusi untuk menentukan kondisi batas dan distribusi temperatur dalam medium.

Persamaan diferensial distribusi temperatur digunakan medium yang dianggap homogen tidak ada gerakan dalam jumlah besar (adveksi) dan distribusi temperatur $T(x, y, z)$ dinyatakan dalam satu sistem koordinat tertentu daerah *differential control volume* dalam koordinat Cartesian ditunjukkan pada gambar 6,



Gambar 6. *Differential control volume* dx, dy dan dz untuk konduksi bahan homogen koordinat cartesian (sumber: Incropera dan Dewitt, 2011).

Selanjutnya, menentukan proses transfer energi yang relevan pada daerah ini. Jika terdapat perbedaan temperatur maka transfer panas secara konduksi terjadi pada setiap permukaan daerah ini (*control surface*). Arah laju konduksi panas tegak lurus untuk setiap *control surface* pada sumbu $x,\ y$ dan z yang dinyatakan oleh variabel $q_x,\ q_y$ dan q_z. Laju konduksi panas pada permukaan berlawanan dapat dinyatakan dengan deret Taylor dan mengabaikan orde yang lebih besar maka bentuk persamaannya adalah sebagai berikut:

$$q_{x+dx} = q_x + \frac{\partial q_x}{\partial x} dx\ , \tag{5}$$

$$q_{y+dy} = q_y + \frac{\partial q_y}{\partial y} dy\ , \tag{6}$$

$$q_{z+dz} = q_z + \frac{\partial q_z}{\partial z} dz\ , \tag{7}$$

Energi yang di transfer dari sumber berhubungan dengan laju energi tergenerasi di dalam medium. Energi tergenerasi ini $(\dot{E_g})$ merupakan hasil konversi suatu bentuk energi (kimia, litsrik, nuklir, dan lainnya) menjadi energi termal. Nilai $\dot{E}_g$ positif jika energi termal tergenerasi dalam material dan negatif jika digunakan. Bentuk persamaan energi tergenerasi adalah

$$\dot{E}_g = \dot{q}\ dxdydz\ , \tag{8}$$

dimana $\dot{q}$ adalah laju energi tergenerasi per unit volume (W/m^3). Selain itu juga terjadi perubahan energi termal yang tersimpan pada bahan dalam *control volume.* Jika bahan tidak mengalami perubahan fasa, maka tidak ada pengaruh dari energi laten sehingga bentuk umum persamaanya,

$$\dot{E}_{st} = \rho c_p \frac{\partial T}{\partial t} dxdydz\ , \tag{9}$$

dimana $\dot{E}_{st}$ adalah energi tersimpan dalam medium. Sedangkan $\rho c_p \frac{\partial T}{\partial t}$ menyatakan laju perubahan energi termal terhadap waktu per unit volume. Menurut Incropera dan Dewitt (2011) berdasarkan persamaan laju perubahan energi dengan menerapkan syarat konservasi energi adalah

$$\dot{E}_{in} + \dot{E}_g - \dot{E}_{out} = \dot{E}_{st} \,, \tag{10}$$

dengan $\dot{E}_{in}$ adalah energi masukan, $\dot{E}_{out}$ adalah energi terdiferensial, $\dot{E}_g$ adalah energi tergenerasi dan $\dot{E}_{st}$ adalah energi tersimpan dalam medium atau bahan. Jika Persamaan (8) dan (9) disubsitusikan maka didapatkan persamaan

$$q_x + q_y + q_z + \dot{q}\; dxdydz - q_{x+dx} - q_{y+dy} - q_{x+dz} = \rho c_p \frac{\partial T}{\partial t} dxdydz \,, \tag{11}$$

dengan mensubtitusi Persamaan (5), (6) dan (7) ke Persamaan (11) maka didapatkan persamaan

$$-\frac{\partial q_x}{\partial x} dx - \frac{\partial q_y}{\partial y} dy - \frac{\partial q_z}{\partial z} dz + \dot{q}\; dxdydz = \rho c_p \frac{\partial T}{\partial t} dxdydz \,, \tag{12}$$

berdasarkan hukum Fourier laju konduksi panas adalah

$$q_x = -k\; dydz \frac{\partial T}{\partial x} \,, \tag{13}$$

$$q_y = -k\; dxdz \frac{\partial T}{\partial y} \,, \tag{14}$$

$$q_z = -k\; dxdy \frac{\partial T}{\partial z} \,, \tag{15}$$

Selanjutnya, mensubtitusikan Persamaan (13), (14) dan (15) ke dalam persamaan (12) dan persamaan (5), (6) dan (7) juga disubsitusikan ke dalam persamaan (12) dan membaginya dengan dimensi *control volume* dx, dy dan dz maka diperoleh persamaan difusi panas sebagai berikut:

$$\frac{\partial}{\partial x}\left(k\ \frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\ \frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\ \frac{\partial T}{\partial z}\right)+\dot{q}\ =\rho c_p\frac{\partial T}{\partial t}\ , \qquad (16)$$

dengan

$\dot{q}$ = energi tergenerasi per unit volume (W/m^3)

ρ = kerapatan (kg/m^3)

k = konstanta kesetimbangan $(W/m\ °C)$

c_p = panas spesifik $(kkal/kg°\mathrm{C})$

(Incropera dan Dewitt, 2011).

Pada persamaan (16) ρ, k dan c_p merupakan konstanta yang mempunyai nilai berbeda-beda pada setiap bahan, untuk menghitung nilai difusivitas termal bahan digunakan persamaan (17)

$$\alpha=\frac{k}{\rho c_p}, \qquad (17)$$

dengan mempertimbangkan temperatur dan mengabaikan sumber internal panas $\dot{q}=0$. Maka diperoleh persamaan difusi panas sebagai berikut,

$$\alpha\left(\frac{\partial^2T}{\partial x^2}+\frac{\partial^2T}{\partial y^2}+\frac{\partial^2T}{\partial z^2}\right)\ =\frac{\partial T}{\partial t}, \qquad (18)$$

(Incropera dan Dewitt, 2011).

7. Metode Beda Hingga

Apabila suatu fungsi f memiliki turunan dari semua tingkatan pada selang $(a-r,\ a+r)$, maka syarat deret Taylor yaitu:

$$f(a)+f^{'}(a)(x-a)+\frac{f^{''}(a)}{2!}(x-a)^2+\frac{f^{'''}(a)}{3!}(x-a)^3\ , \qquad (19)$$

fungsi pada selang tersebut adalah

$$\lim_{n\to\infty} R_n(x)=0\ , \qquad (20)$$

dengan $R_n(x)$ adalah suku sisa dalam rumus Taylor sehingga

$$R_n(x)=\frac{f^{(n+1)}(c)}{(n+1)!}(x-a)^{n-1}\ , \qquad (21)$$

dan c merupakan suatu bilangan dalam selang $(a-r,\ a+r)$

(Purcel dan Varberg, 1990).

Untuk mendapatkan metode beda hingga dibutuhkan deret Taylor. Deret Taylor fungsi satu variabel sekitar x diberikan sebagai berikut:

$$f(x+\Delta x)=f(x)+f^{'}(x)\Delta x+\frac{f^{''}(x)}{2!}\Delta x^2+\cdots\ , \qquad (22)$$

atau

$$f(x-\Delta x)=f(x)-f^{'}(x)\Delta x+\frac{f^{''}(x)}{2!}\Delta x^2-\cdots\ , \qquad (23)$$

deret Taylor ini merupakan dasar pemikiran metode beda hingga untuk menyelesaikan persamaan diferensial parsial secara numerik.

Dari deret Taylor ini dikenal tiga pendekatan beda hingga:

a. pendekatan beda maju (*forward difference*)

$$f'(x) \approx \frac{f(x+\Delta x)-f(x)}{h}, \tag{24}$$

b. pendekatan beda mundur (*backward difference*)

$$f'(x) \approx \frac{f(x)-f(x-\Delta x)}{h}, \tag{25}$$

c. pendekatan beda pusat (*center difference*)

$$f'(x) \approx \frac{f(x+\Delta x)-f(x-\Delta x)}{2h}, \tag{26}$$

(Holman, 1997).

Sedangkan untuk turunan kedua ditinjau dari deret Taylor hingga nilai h yang berderajat dua. Pemotongan dilakukan pada Δx yang berderajat tiga (Darmin dan Hanafi, 2010).

Deret Taylor akan memberikan perkiraan fungsi dengan benar jika semua suku dari deret tersebut diperhitungkan. Namun dalam praktik hanya beberapa suku saja yang diperhitungkan sehingga hasil perkiraan tidak seperti pada penyelesaian analitis. Kesalahan yang tidak diperhitungkannya suku-suku terakhir dari deret Taylor yang disebut juga dengan kesalahan pemotongan (*trunction error* R_n) yang ditulis:

$$R_n = O(\Delta x^{n+1}), \tag{27}$$

indeks n menunjukkan bahwa deret yang diperhitungkan adalah sampai pada suku ke n, sedangkan subskrip $n+1$ menunjukkan kesalahan pemotongan mempunyai orde $n+1$. Notasi $O(\Delta x^{n+1})$ berarti bahwa kesalahan pemotongan mempunyai orde Δx^{n+1} atau kesalahan adalah sebanding dengan langkah ruang pangkat $n+1$. Kesalahan pemotongan tersebut adalah kecil apabila:

a. interval Δx adalah kecil; dan
b. memperhitungkan lebih banyak suku dari deret Taylor.

Sehingga perkiraan orde satu besarnya kesalahan pemotongan adalah:

$$O(\Delta x^2) = T'' x_i \frac{\Delta x^2}{2!} + T''' x_i \frac{\Delta x^2}{3!} + \cdots, \tag{28}$$

(Holman, 1997).

Secara umum untuk mencari nilai galat relatif menggunakan persamaan sebagai berikut,

$$Galat\ Relatif = \frac{|Nilai\ Analitis - Nilai\ Numeris\ |}{Nilai\ Analitis}$$

8. Metode Beda Hingga Keadaan *Transient* Bahan Homogen

Metode beda hingga sangat sering digunakan untuk mencari solusi persamaan diferensial parsial (PDP). Hal ini disebabkan mudahnya mendekati PDP dengan pendekatan deret Taylor dan diperoleh persamaan beda. Idenya adalah membawa domain PDP ke dalam domain komputasi yang berupa *grid*. Untuk menyederhanakan penulisan, sering dituliskan dengan notasi indeks. Indeks *subscript* pertama, kedua dan ketiga sebagai variabel ruang dan *subscript* keempat sebagai variabel waktu.

Bentuk satu dimensi ditulis pada persamaan (29),

$$T_t(x,t) = T_{xx}(x,t), \tag{29}$$

untuk dua dimensi ditulis pada persamaan (30),

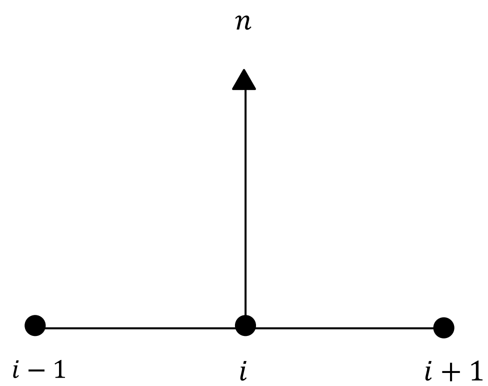
$$T_t(x,y,t) = T_{xx}(x,y,t) + T_{yy}(x,y,t), \tag{30}$$

dan tiga dimensi ditulis pada persamaan (31),

$$T_t(x,y,z,t) = T_{xx}(x,y,z,t) + T_{yy}(x,y,z,t) + T_{zz}(x,y,z,t)\ , \tag{31}$$

a. Metode Eksplisit

Metode eksplisit sering disebut juga dengan metode *forward time center space* (FTCS). Pada metode ini beda maju terhadap waktu (*forward time*) diterapkan u_t dengan akurasi $O(\Delta x^2, \Delta y^2, \Delta z^2)$. Skema ekspisit ini dapat dilihat pada Gambar 7.



Gambar 7. Skema eksplisit.

$$\frac{\partial T(x,y,z,t)}{\partial t} = T_t(x,y,z,t)\ , \tag{32}$$

$$\left(\frac{\partial^2 T(x,y,z,t)}{\partial x^2}\right) = T_{xx}(x,y,z,t)\ , \tag{33}$$

$$\left(\frac{\partial^2 T(x,y,z,t)}{\partial y^2}\right) = T_{yy}(x,y,z,t)\ , \tag{34}$$

$$\left(\frac{\partial^2 T(x,y,z,t)}{\partial z^2}\right) = T_{zz}(x,y,z,t)\,, \tag{35}$$

$$T_t(x,y,z,t) = \frac{T_{i,j,k}^{n+1} - T_{i,j,k}^{n}}{\Delta t}\,, \tag{35}$$

$$T_{xx}(x,y,z,t) = \frac{T_{i+1,j,k}^{n} - 2T_{i,j,k}^{n} + T_{i-1,j,k}^{n}}{\Delta x^2}\,, \tag{36}$$

$$T_{yy}(x,y,z,t) = \frac{T_{i,j+1,k}^{n} - 2T_{i,j,k}^{n} + T_{i,j-1,k}^{n}}{\Delta y^2}\,, \tag{37}$$

$$T_{zz}(x,y,z,t) = \frac{T_{i,j,k+1}^{n} - 2T_{i,j,k}^{n} + T_{i,j,k-1}^{n}}{\Delta z^2}\,, \tag{38}$$

kemudian dengan dengan menerapkan persamaan (31) dengan menambahkan nilai dfusivitas bahan α,

$$T_t(x,y,z,t) = \alpha\left\{T_{xx}\ (x,y,z,t) +\ T_{yy}(x,y,z,t) + T_{zz}(x,y,z,t)\right\}, \tag{39}$$

maka diperoleh persamaan (40) sebagai berikut,

$$\frac{T_{i,j,k}^{n+1} - T_{i,j,k}^{n}}{\Delta t} = \alpha\left\{\frac{T_{i+1,j,k}^{n} - 2T_{i,j,k}^{n} + T_{i-1,j,k}^{n}}{\Delta x^2} + \frac{T_{i,j+1,k}^{n} - 2T_{i,j,k}^{n} + T_{i,j-1,k}^{n}}{\Delta y^2} + \frac{T_{i,j,k+1}^{n} - 2T_{i,j,k}^{n} + T_{i,j,k-1}^{n}}{\Delta z^2}\right\}, \tag{40}$$

dengan menuliskan ruas kiri pada $T_{i,j,k}^{n+1}$ yang merupakan titik yang belum diketahui nilainya, persamaan (40) ditulis menjadi

$$T_{i,j,k}^{n+1} = T_{i,j,k}^{n} +\ \Delta t.\alpha\left\{\frac{T_{i+1,j,k}^{n} - 2T_{i,j,k}^{n} + T_{i-1,j,k}^{n}}{\Delta x^2} + \frac{T_{i,j+1,k}^{n} - 2T_{i,j,k}^{n} + T_{i,j-1,k}^{n}}{\Delta y^2} + \frac{T_{i,j,k+1}^{n} - 2T_{i,j,k}^{n} + T_{i,j,k-1}^{n}}{\Delta z^2}\right\},$$

(41)

$$T_{i,j,k}^{n+1} = T_{i,j,k}^{n} + \frac{\Delta t.\alpha}{\Delta x^2}\left(T_{i+1,j,k}^{n} - 2T_{i,j,k}^{n} + T_{i-1,j,k}^{n}\right) + \frac{\Delta t.\alpha}{\Delta y^2}\left(T_{i,j+1,k}^{n} - 2T_{i,j,k}^{n} + T_{i,j-1,k}^{n}\right) + \frac{\Delta t.\alpha}{\Delta z^2}\left(T_{i,j,k+1}^{n} - 2T_{i,j,k}^{n} + T_{i,j,k-1}^{n}\right),$$

(42)

Δt, α, $\Delta x^2, \Delta y^2$ dan Δz^2 pada bahan homogen memiliki nilai variabel yang dapat dimudahkan dalam perhitungan numerik, maka digunakan subtitusi $r = \frac{\Delta t.\alpha}{\Delta x^2} = \frac{\Delta t.\alpha}{\Delta y^2} = \frac{\Delta t.\alpha}{\Delta z^2}$ sehingga didapatkan penyederhanaan dari Persamaan (42),

$$T_{i,j,k}^{n+1} = T_{i,j,k}^{n} + r\left\{\left(T_{i+1,j,k}^{n} - 2T_{i,j,k}^{n} + T_{i-1,j,k}^{n}\right) + \left(T_{i,j+1,k}^{n} - 2T_{i,j,k}^{n} + T_{i,j-1,k}^{n}\right) + \left(T_{i,j,k+1}^{n} - 2T_{i,j,k}^{n} + T_{i,j,k-1}^{n}\right)\right\},$$

(43)

sehingga didapatkan persamaan akhir skema eksplisit tiga dimensi,

$$T_{i,j,k}^{n+1} = (1-6r)T_{i,j,k}^{n} + r\left(T_{i+1,j,k}^{n} + T_{i-1,j,k}^{n} + T_{i,j+1,k}^{n} + T_{i,j-1,k}^{n} + T_{i,j,k+1}^{n} + T_{i,j,k-1}^{n}\right),$$

(44)

untuk mendapatkan metode eksplisit tiga dimensi penuh stabilitas dan konvergensi dapat diperoleh $r \leq \frac{1}{6}$ (Sailah, 2010). Menggunakan perhitungan yang penurunan yang sama dengan metode eksplisit tiga dimensi maka diperoleh metode eksplisit dua dimensi sebagai berikut,

$$T_{i,j,k}^{n+1} = (1-4r)T_{i,j,k}^{n} + r\left(T_{i+1,j,k}^{n} + T_{i-1,j,k}^{n} + T_{i,j+1,k}^{n} + T_{i,j-1,k}^{n}\right),$$

(45)

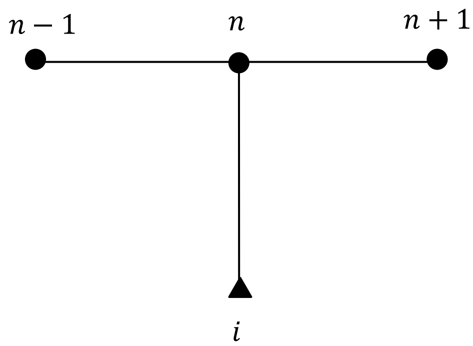
untuk mendapatkan metode eksplisit dua dimensi penuh stabilitas dan konvergensi dapat diperoleh $r \leq \frac{1}{4}$ (Sailah, 2010). Sedangkan metode eksplisit satu dimensi sebagai berikut,

$$T_{i,j,k}^{n+1} = (1-2r)T_{i,j,k}^{n} + r\left(T_{i+1,j,k}^{n} + T_{i-1,j,k}^{n}\right), \tag{46}$$

metode eksplisit satu dimensi penuh stabilitas dan konvergensi dapat diperoleh $r \leq \frac{1}{2}$ (Sailah, 2010).

b. Metode Implisit

Metode implisit sering disebut juga dengan metode *Backward Time Center Space* (BTCS) dapat dilihat pada Gambar 8. Persamaan beda implisit ini menerapkan beda mundur terhadap waktu (*backward time*) pada T_t dengan akurasi $O(\Delta t, \Delta x^2, \Delta y^2, \Delta z^2)$.



Gambar 8. Skema implisit.

$$T_t(x,y,z,t) = \frac{T_{i,j,k}^{n+1} - T_{i,j,k}^{n}}{\Delta t}, \tag{47}$$

$$T_{xx}(x,y,z,t) = \frac{T_{i+1,j,k}^{n+1} - 2T_{i,j,k}^{n+1} + T_{i-1,j,k}^{n+1}}{\Delta x^2}, \tag{48}$$

$$T_{yy}(x,y,z,t) = \frac{T_{i,j+1,k}^{n+1} - 2T_{i,j,k}^{n+1} + T_{i,j-1,k}^{n+1}}{\Delta y^2}, \quad (49)$$

$$T_{zz}(x,y,z,t) = \frac{T_{i,j,k+1}^{n+1} - 2T_{i,j,k}^{n+1} + T_{i,j,k-1}^{n+1}}{\Delta z^2}, \quad (50)$$

Kemudian dengan dengan menerapkan Persamaan (31) dengan menambahkan nilai dfusivitas bahan α sehingga diperoleh,

$$\frac{T_{i,j,k}^{n+1} - T_{i,j,k}^{n}}{\Delta t} = \alpha \left\{ \frac{T_{i+1,j,k}^{n+1} - 2T_{i,j,k}^{n+1} + T_{i-1,j,k}^{n+1}}{\Delta x^2} + \frac{T_{i,j+1,k}^{n+1} - 2T_{i,j,k}^{n+1} + T_{i,j-1,k}^{n+1}}{\Delta y^2} + \frac{T_{i,j,k+1}^{n+1} - 2T_{i,j,k}^{n+1} + T_{i,j,k-1}^{n+1}}{\Delta z^2} \right\}. \quad (51)$$

Kemudian, menuliskan ruas kiri pada $T_{i,j,k}^{n}$ yang merupakan titik yang belum diketahui nilainya, menjadi

$$T_{i,j,k}^{n} = T_{i,j,k}^{n+1} + \Delta t.\alpha \left\{ \left(\frac{-T_{i+1,j,k}^{n+1} + 2T_{i,j,k}^{n+1} - T_{i-1,j,k}^{n+1}}{\Delta x^2} \right) + \left(\frac{-T_{i,j+1,k}^{n+1} + 2T_{i,j,k}^{n+1} - T_{i,j-1,k}^{n+1}}{\Delta y^2} \right) + \left(\frac{-T_{i,j,k+1}^{n+1} + 2T_{i,j,k}^{n+1} - T_{i,j,k-1}^{n+1}}{\Delta z^2} \right) \right\}, \quad (52)$$

$$T_{i,j,k}^{n} = T_{i,j,k}^{n+1} + \frac{\Delta t.\alpha}{\Delta x^2} \left(-T_{i+1,j,k}^{n+1} + 2T_{i,j,k}^{n+1} - T_{i-1,j,k}^{n+1} \right) + \frac{\Delta t.\alpha}{\Delta y^2} \left(-T_{i,j+1,k}^{n+1} + 2T_{i,j,k}^{n+1} - T_{i,j-1,k}^{n+1} \right) + \frac{\Delta t.\alpha}{\Delta z^2} \left(-T_{i,j,k+1}^{n+1} + 2T_{i,j,k}^{tn+1} - T_{i,j,k-1}^{n+1} \right),$$

(53)

$\Delta t,\ \alpha,\ \Delta x^2, \Delta y^2$ dan Δz^2 pada bahan homogen memiliki nilai variabel yang dapat dimudahkan dalam perhitungan numerik, maka digunakan subtitusi $r = \frac{\Delta t.\alpha}{\Delta x^2} = \frac{\Delta t.\alpha}{\Delta y^2} = \frac{\Delta t.\alpha}{\Delta z^2}$ sehingga didapatkan penyederhanaan dari Persamaan (53)

$$T_{i,j,k}^{n} = T_{i,j,k}^{n+1} + r\left\{\left(-T_{i+1,j,k}^{n+1} + 2T_{i,j,k}^{n+1} - T_{i-1,j,k}^{n+1}\right) + \left(-T_{i,j+1,k}^{n+1} + 2T_{i,j,k}^{n+1} - T_{i,j-1,k}^{n+1}\right) + \left(-T_{i,j,k+1}^{n+1} + 2T_{i,j,k}^{n+1} - T_{i,j,k-1}^{n+1}\right)\right\},$$

(54)

kemudian Persamaan (54) ditulis kembali, sehingga didapatkan persamaan akhir skema implisit tiga dimensi sebagai berikut,

$$T_{i,j,k}^{n} = (1+6r)T_{i,j,k}^{n+1} - r\left(T_{i+1,j,k}^{n+1} + T_{i-1,j,k}^{n+1} + T_{i,j+1,k}^{n+1} + T_{i,j-1,k}^{n+1} + T_{i,j,k+1}^{n+1} + T_{i,j,k-1}^{n+1}\right).$$

(55)

Menggunakan perhitungan yang penurunan yang sama dengan metode eksplisit tiga dimensi maka diperoleh metode implisit dua dimensi sebagai berikut,

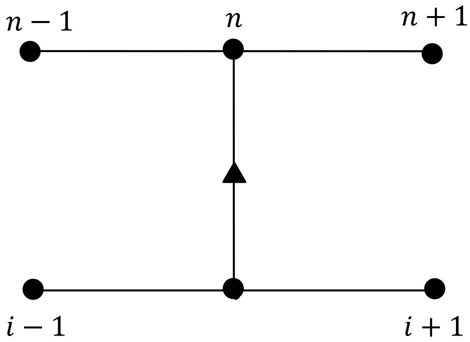
$$T_{i,j,k}^{n} = (1+4r)T_{i,j,k}^{n+1} - r\left(T_{i+1,j,k}^{n+1} + T_{i-1,j,k}^{n+1} + T_{i,j+1,k}^{n+1} + T_{i,j-1,k}^{n+1}\right), \quad (56)$$

Sedangkan metode implisit dua dimensi sebagai berikut,

$$T_{i,j,k}^{n} = (1+2r)T_{i,j,k}^{n+1} - r\left(T_{i+1,j,k}^{n+1} + T_{i-1,j,k}^{n+1}\right), \quad (57)$$

c. Metode Crank-Nicolson

Dengan menerapkan beda pusat terhadap waktu (*center time*) untuk menghampiri T_t di titik grid $i, j, k, n + \frac{1}{2}$ dapat dilihat pada Gambar 9.



Gambar 9. Skema Crank-Nicolson.

Menerapkan beda pusat terhadap T_{xx}, T_{yy} dan T_{zz} di titik grid $i, j, k, n + 1$ (pada waktu $n + 1$) diperoleh

$$T_{xx}(x, y, z, t) = \frac{T_{i+1,j,k}^{n+1} - 2T_{i,j,k}^{n+1} + T_{i-1,j,k}^{n+1}}{\Delta x^2}, \tag{58}$$

$$T_{yy}(x, y, z, t) = \frac{T_{i,j+1,k}^{n+1} - 2T_{i,j,k}^{n+1} + T_{i,j-1,k}^{n+1}}{\Delta y^2}, \tag{59}$$

$$T_{zz}(x, y, z, t) = \frac{T_{i,j,k+1}^{n+1} - 2T_{i,j,k}^{n+1} + T_{i,j,k-1}^{n+1}}{\Delta z^2}, \tag{60}$$

dan untuk T_{xx}, T_{yy} dan T_{zz} di titik grid i, j, k, n (pada waktu n) diperoleh

$$T_{xx}(x, y, z, t) = \frac{T_{i+1,j,k}^{n} - 2T_{i,j,k}^{n} + T_{i-1,j,k}^{n}}{\Delta x^2}, \tag{61}$$

$$T_{yy}(x, y, z, t) = \frac{T_{i,j+1,k}^{n} - 2T_{i,j,k}^{n} + T_{i,j-1,k}^{n}}{\Delta y^2}, \tag{62}$$

$$T_{zz}(x, y, z, t) = \frac{T_{i,j,k+1}^{n} - 2T_{i,j,k}^{n} + T_{i,j,k-1}^{n}}{\Delta z^2}, \tag{63}$$

menerapkan Persamaan (31) dengan menambahkan nilai dfusivitas bahan α sehingga diperoleh persamaan beda untuk metode Crank-Nicolson,

$$\frac{T_{i,j,k}^{n+1}-T_{i,j,k}^{n}}{\Delta t}=\frac{\alpha}{2}\left\{\frac{T_{i+1,j,k}^{n}-2T_{i,j,k}^{n}+T_{i-1,j,k}^{n}}{\Delta x^2}+\frac{T_{i,j+1,k}^{n}-2T_{i,j,k}^{n}+T_{i,j-1,k}^{n}}{\Delta y^2}\right.$$
$$+\frac{T_{i,j,k+1}^{n}-2T_{i,j,k}^{n}+T_{i,j,k-1}^{n}}{\Delta z^2}+\frac{T_{i+1,j,k}^{n+1}-2T_{i,j,k}^{n+1}+T_{i-1,j,k}^{n+1}}{\Delta x^2}$$
$$\left.+\frac{T_{i,j+1,k}^{n+1}-2T_{i,j,k}^{n+1}+T_{i,j-1,k}^{n+1}}{\Delta y^2}+\frac{T_{i,j,k+1}^{n+1}-2T_{i,j,k}^{n+1}+T_{i,j,k-1}^{n+1}}{\Delta z^2}\right\},$$

(64)

Persamaan (64) ditulis kembali menjadi

$$T_{i,j,k}^{n+1}-T_{i,j,k}^{n}=\frac{\Delta t.\alpha}{2}\left\{\frac{T_{i+1,j,k}^{n}-2T_{i,j,k}^{n}+T_{i-1,j,k}^{n}}{\Delta x^2}+\frac{T_{i,j+1,k}^{n}-2T_{i,j,k}^{n}+T_{i,j-1,k}^{n}}{\Delta y^2}\right.$$
$$+\frac{T_{i,j,k+1}^{n}-2T_{i,j,k}^{n}+T_{i,j,k-1}^{n}}{\Delta z^2}+\frac{T_{i+1,j,k}^{n+1}-2T_{i,j,k}^{n+1}+T_{i-1,j,k}^{n+1}}{\Delta x^2}$$
$$\left.+\frac{T_{i,j+1,k}^{n+1}-2T_{i,j,k}^{n+1}+T_{i,j-1,k}^{n+1}}{\Delta y^2}+\frac{T_{i,j,k+1}^{n+1}-2T_{i,j,k}^{n+1}+T_{i,j,k-1}^{n+1}}{\Delta z^2}\right\},$$

(65)

$\Delta t,\ \alpha,\ \Delta x^2, \Delta y^2$ dan Δz^2 pada bahan homogen memiliki nilai variabel yang dapat dimudahkan dalam perhitungan numerik, maka digunakan subtitusi $r=\frac{\Delta t.\alpha}{\Delta x^2}=\frac{\Delta t.\alpha}{\Delta y^2}=\frac{\Delta t.\alpha}{\Delta z^2}$ sehingga didapatkan penyederhanaan dari Persamaan (65)

$$2\left(T_{i,j,k}^{n+1}-T_{i,j,k}^{n}\right)= r\left\{T_{i+1,j,k}^{n}-2T_{i,j,k}^{n}+T_{i-1,j,k}^{n}+T_{i,j+1,k}^{n}-2T_{i,j,k}^{n}+\right.$$
$$T_{i,j-1,k}^{n}+T_{i,j,k+1}^{n}-2T_{i,j,k}^{n}+T_{i,j,k-1}^{n}+T_{i+1,j,k}^{n+1}-2T_{i,j,k}^{n+1}+T_{i-1,j,k}^{n+1}+$$
$$\left.T_{i,j+1,k}^{n+1}-2T_{i,j,k}^{n+1}+T_{i,j-1,k}^{n+1}+T_{i,j,k+1}^{n+1}-2T_{i,j,k}^{n+1}+T_{i,j,k-1}^{n+1}\right\},$$

(66)

dengan mengumpulkan waktu $n+1$ sebelah kiri dan waktu n sebelah kanan, persamaan akhir tiga dimensi Crank-Nicolson menjadi,

$$(2+6r)T_{i,j,k}^{n+1} - r\left(T_{i+1,j,k}^{n+1} + T_{i-1,j,k}^{n+1} + T_{i,j+1,k}^{n+1} + T_{i,j-1,k}^{n+1} + T_{i,j,k+1}^{n+1} + T_{i,j,k-1}^{n+1}\right) = (2-6r)T_{i,j,k}^{n} + r\left(T_{i+1,j,k}^{n} + T_{i-1,j,k}^{n} + T_{i,j+1,k}^{n} + T_{i,j-1,k}^{n} + T_{i,j,k+1}^{n} + T_{i,j,k-1}^{n}\right). \quad (67)$$

Menggunakan perhitungan yang penurunan yang sama dengan metode Crank-Nicolson tiga dimensi maka diperoleh metode Crank-Nicolson dua dimensi sebagai berikut,

$$(2+4r)T_{i,j,k}^{n+1} - r\left(T_{i+1,j,k}^{n+1} + T_{i-1,j,k}^{n+1} + T_{i,j+1,k}^{n+1} + T_{i,j-1,k}^{n+1}\right) = (2-4r)T_{i,j,k}^{n} + r\left(T_{i+1,j,k}^{n} + T_{i-1,j,k}^{n} + T_{i,j+1,k}^{n} + T_{i,j-1,k}^{n}\right), \quad (68)$$

Sedangkan metode Crank-Nicolson satu dimensi sebagai berikut,

$$(2+2r)T_{i,j,k}^{n+1} - r\left(T_{i+1,j,k}^{n+1} + T_{i-1,j,k}^{n+1}\right) = (2-4r)T_{i,j,k}^{n} + r\left(T_{i+1,j,k}^{n} + T_{i-1,j,k}^{n}\right). \quad (69)$$

Sedangkan persamaan analitis satu, dua dan tiga dimensi berturut-turut menurut Gockenbach (2009) bahan homogen keadaan *transient* adalah sebagai berikut,

$$T(i,n) = exp\left(-\frac{\pi^2 \alpha t(n)}{l^2}\right) sin\left(\frac{\pi x(i)}{l}\right) \quad (70)$$

$$T(i,j,n) = exp\left(-\frac{\pi^2 \alpha t(n)}{l^2}\right) sin\left(\frac{\pi x(i)}{l}\right) sin\left(\frac{\pi y(j)}{l}\right) \quad (71)$$

$$T(i,j,k,n) = exp\left(-\frac{\pi^2 \alpha t(n)}{l^2}\right) sin\left(\frac{\pi x(i)}{l}\right) sin\left(\frac{\pi y(j)}{l}\right) sin\left(\frac{\pi z(k)}{l}\right) \quad (72)$$

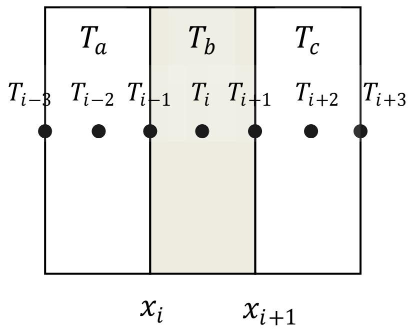
9. Metode Beda Hingga Keadaan *Transient* Bahan *Multilayer*

Metode beda hingga pada bahan *multilayer* satu dimensi dikembangkan oleh Antonopoulos dan Vrachopoulos (1996); Hickson, Barry dan Sidhu (2009); dan Hickson, Barry, Mercer, dan Sidhu (2011). Hickson, Barry dan Sidhu (2011) meneliti difusi satu dimensi pada bahan *multilayer* dengan kesesuaian difusivitas, kesesuaian konduktivitas dan kesesuaian kondisi batas menggunakan metode eksplisit. Kesesuaian difusivitas ini diasumsikan bahwa adanya kekontinuan suhu dan *flux* pada penghubung antar *layer*, kesesuaian konduktivitas diasumsikan penghubung antar *layer* memiliki rata-rata konduktivitas dan kesesuaian kondisi batas merupakan pengembangan pada kesesuaian konduktivitas ketika jarak titik sampel suhu pada *layer* menggunakan jarak titik berbeda. Menggunakan kesesuaian difusivitas yang dapat dilihat pada Gambar 10, Persamaan (18) ditulis kembali menjadi dalam bentuk satu dimensi

$$\frac{\partial}{\partial x}\alpha_i\left(\frac{\partial T_i}{\partial x}\right) = \frac{\partial T_i}{\partial t}, \qquad i = 1,2,3\ldots,n \tag{73}$$

$$T_a = T_b;\ T_b = T_c \tag{74}$$

$$\alpha_1\left(\frac{\partial T_a}{\partial x}\right) = \alpha_2\left(\frac{T_b}{\partial x}\right) \text{ dan } \alpha_2\left(\frac{T_b}{\partial x}\right) = \alpha_3\left(\frac{T_c}{\partial x}\right) \tag{75}$$



Gambar 10. Skema diagram *grid-point* arah sumbu$-x$.

Pada *interface* $x = x_i$ pada *layer* menggunakan standar waktu orde pertama dan jarak beda hingga orde dua, jarak beda hingga pada titik T_{i-2} memberikan,

$$\frac{T_{i-2}}{\partial t} = \alpha_1 \left(\frac{T_{i-3} - 2T_{i-2} + T_{i-1}}{\Delta x^2} \right), \qquad (76)$$

dimana T_{i-2} adalah suhu pada titik ruang T_{i-2} pada layer 1, sedangkan pada titik *interface* menggunakan beda tengah untuk Persamaan (74) memberikan

$$\frac{T_{i-1}}{\partial t} = \frac{\alpha_2 \left(\frac{T_b}{\partial x} \right) - \alpha_1 \left(\frac{T_a}{\partial x} \right)}{\Delta x}, \qquad (77)$$

menggunakan orde pertama beda maju dan beda mundur memberikan

$$\frac{T_{i-1}}{\partial t} = \frac{\alpha_2 \left(\frac{T_i - T_{i-1}}{\Delta x} \right) - \alpha_1 \left(\frac{T_{i-1} - T_{i-2}}{\Delta x} \right)}{\Delta x}, \qquad (78)$$

$$\frac{T_{i-1}}{\Delta t} = \frac{\alpha_{2\,T_i} - (\alpha_2 + \alpha_1) T_{i-1} + \alpha_1 T_{i-2}}{\Delta x^2}, \qquad (79)$$

(Hickson, Barry dan Sidhu, 2011).

Kemudian Persamaan (79) ditulis kembali menjadi

$$T_{i-1} = \frac{\Delta t \left(\alpha_{2\,T_i} - (\alpha_2 + \alpha_1) T_{i-1} + \alpha_1 T_{i-2} \right)}{\Delta x^2}, \qquad (80)$$

dan mensubtitusi $r = \frac{\Delta t}{\Delta x^2}$ didapatkan

$$T_{i-1} = r\left(\alpha_{2\,T_i} - (\alpha_2 + \alpha_1) T_{i-1} + \alpha_1 T_{i-2} \right), \qquad (81)$$

berdasarkan Persamaan (81) maka suhu pada titik ruang T_i pada layer 2

$$\frac{T_i}{\partial t} = \alpha_2 \left(\frac{T_{i-1} - T_i + T_{i+1}}{\Delta x^2} \right), \qquad (82)$$

suhu pada titik ruang T_{i+2} pada layer 3

$$\frac{T_{i+1}}{\partial t} = \frac{\alpha_3\left(\frac{T_{i+2}-T_{i+1}}{\Delta x}\right)-\alpha_2\left(\frac{T_{i+1}-T_{i}}{\Delta x}\right)}{\Delta x}, \qquad (83)$$

kemudian persamaan (83) ditulis kembali,

$$\frac{T_{i+1}}{\Delta t} = \frac{\alpha_3\, T_{i+2} - (\alpha_3+\alpha_2)T_{i+1}+\alpha_2 T_i}{\Delta x^2}, \qquad (84)$$

menggunakan metode yang sama dengan T_{i-2} persamaan (84) menjadi,

$$\frac{T_{i+2}}{\partial t} = \alpha_3\left(\frac{T_{i+3} - T_{i+2} + T_{i+1}}{\Delta x^2}\right). \qquad (85)$$

kemudian persamaan (85) ditulis kembali menjadi,

$$T_{i+2} = r\big(\alpha_{2\,T_{i+1}} - (\alpha_3 + \alpha_2)T_{i+2} + \alpha_3 T_{i+2}\big), \qquad (86)$$

10. Metode Beda Hingga Keadaan *Steady State*

Metode beda hingga keadaan *steady state* merupakan bagian dari persamaaan eleptik yang berhubungan dengan masalah kesetimbangan atau kondisi permanen tidak bergantung waktu.

Persamaan dalam tipe ini adalah persamaan Laplace dalam dua dimensi,

$$\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) = 0, \qquad (87)$$

(Incropera dan Dewitt, 2011).

Menggunakan Persamaan (33) dan (34) dengan $T_t(x, y, z, t) = 0$, sehingga Persamaan(87) menjadi,

$$\frac{T_{i+1,j} - 2T_{i,j} + T_{i-1,j,k}}{\Delta x^2} + \frac{T_{i,j+1} - 2T_{i,j,k} + T_{i,j-1}}{\Delta y^2} = 0, \qquad (88)$$

dengan $\Delta x^2 = \Delta y^2 = 1$, maka $T_t(x, y, z, t)$ ditulis kembali menjadi,

$$T_{i,j} = \frac{T_{i+1,j} + T_{i-1,j,k} + T_{i,j+1} + T_{i,j-1}}{4}, \qquad (89)$$

Penerapan metode SOR pada persamaan (89) diperoleh persamaan distribusi suhu sebagai berikut,

$$T_{i,j} = (1-\omega)T_{i,j} + \omega\left(\frac{T_{i+1,j} + T_{i-1,j,k} + T_{i,j+1} + T_{i,j-1}}{4}\right), \qquad (90)$$

dengan ω adalah koefesien relaksasi.

11. Matlab

Matlab merupakan *software* yang andal menyelesaikan berbagai permasalahan komputasi numerik yang diproduksi oleh The Mathwork, Inc. Solusi dari permasalahan yang berhubungan dengan vektor dan matriks dapat diselesaikan dengan mudah dan sederhana menggunakan software ini. Bahkan *software* ini dapat memecahkan invers matriks dan persamaan linear dengan cepat dan mudah sekali.

Beberapa *toolbox* yang disediakan Matlab mampu menyelesaikan kasus yang berhubungan dengan:

a. *image Processing* menyediakan berbagai fungsi yang berhubugan dengan pengolahan citra;

b. *signal Processing* menyediakan berbagai fungsi yang berhubungan dengan pengolahan sinyal; dan
c. *neural Network* menyediakan berbagai fungsi yang berhubungan dengan jaringan saraf tiruan (Irawan, 2012).

System requirements Matlab 8.1 yang dimiliki komputer diantaranya adalah *Processor* minimal *Intel Pentium* IV (mendukung SSE2) atau AMD yang sudah mendukung SSE2, RAM minimal 1024 MB (1 GB), ruang kosong pada *hard disk* minimal 1 GB dan sistem operasi *Windows XP Service Pack* 3 hingga versi terbaru yaitu *Windows* 8 (The MathWorks, 2013).

BAB III

METODE PENELITIAN

A. Waktu dan Tempat Pelaksanaan

Penelitian ini dilaksanakan Desember 2015 sampai dengan Juli 2016 di Laboratorium Pemodelan Fisika Jurusan Fisika Fakultas Matematika dan Ilmu Pengetahuan Alam Universitas Lampung.

B. Alat dan Bahan

Alat dan bahan yang digunakan dalam penelitian ini antara lain:

1. Laptop

Spesifikasi laptop yang digunakan pada penelitian ini dapat dilihat pada tabel 5 berikut.

Tabel 5. Spesifikasi Teknis Penelitian.

Deskripsi	Spesifikasi
Processor	Intel(R)Core(TM) i5
RAM	2048MB
HardDisk	320 GB
Operating System	Windows 7 Ultimate 32-bit

2. *Software*

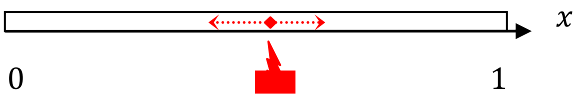
Software yang digunakan pada penelitian ini adalah Matlab 8.1.

C. Prosedur Penelitian

1. Penyusunan Model Satu Dimensi Bahan Homogen dan *Multilayer* Keadaan *Transient*

a. Satu Dimensi Bahan Homogen Keadaan *Transient*

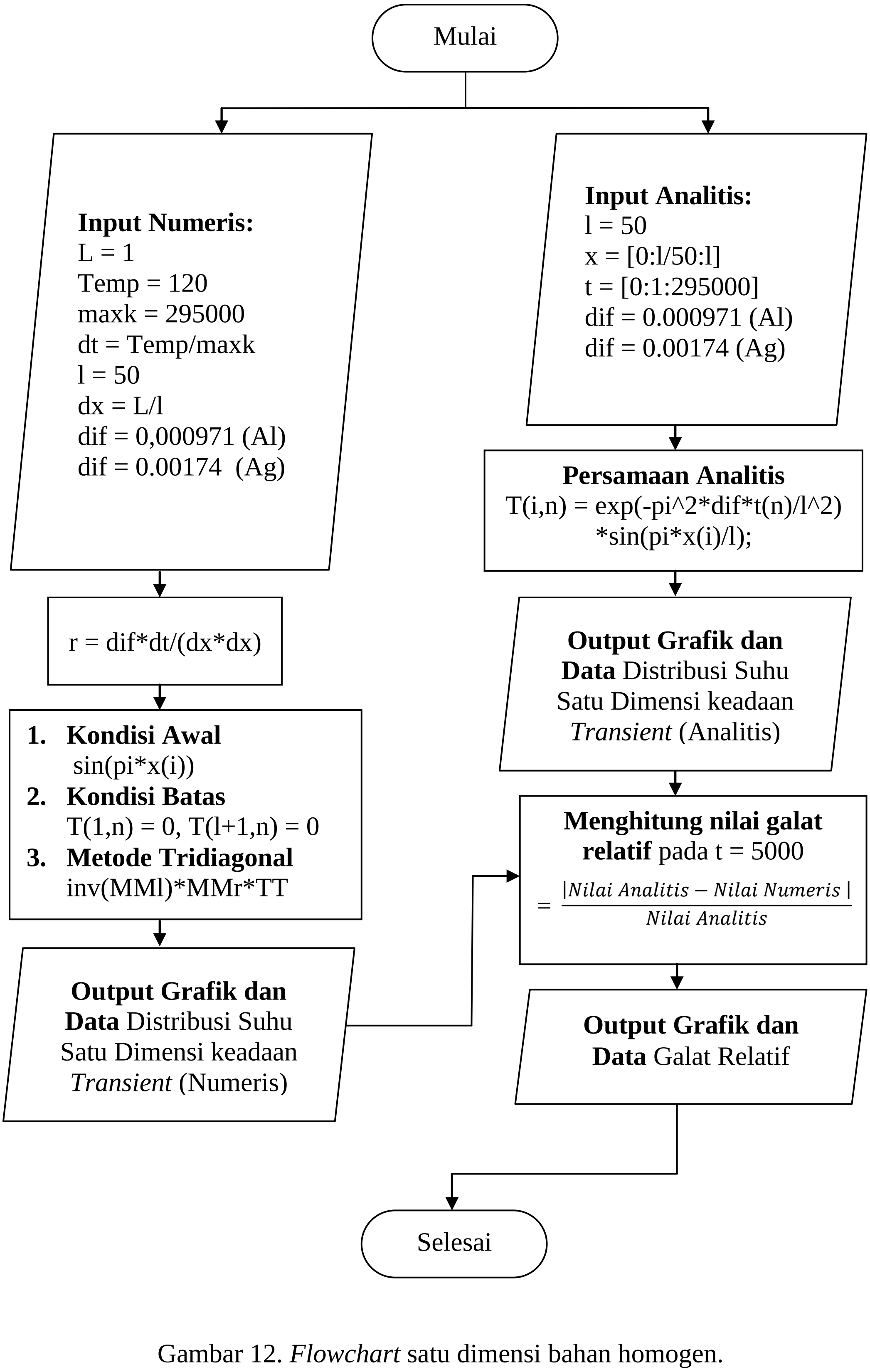
Bentuk model satu dimensi bahan homogen yang digunakan seperti pada Gambar 11.



Gambar 11. Model satu dimensi bahan homogen.

Persamaan satu dimensi bahan homogen yang digunakan pada penelitian ini menggunakan skema Crank-Nicolson yang penyelesainnya menggunakan persamaan (69) pada penyelesaian numeris dan menggunakan Persamaan (70) untuk persamaan analitis.

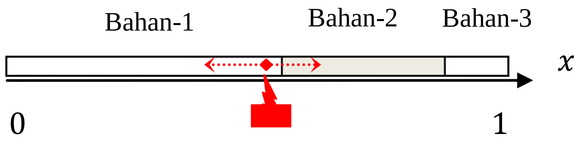
Penyelesaian secara numeris menggunakan suhu awal $T(i, 1) = sin(\pi x)$, syarat batas *Dirichlet* bernilai 0 pada kedua ujung bahan, panjang sumbu-*x* adalah 1 dan panjang temperatur 120 dengan bahan yang dimodelkan adalah Aluminium dan Perak dengan difusivitas bahan keduanya adalah 0,000971 dan 0,00174, adapun *flowchart* visualisasi distribusi suhu satu dimensi pada bahan homogen ini dapat di lihat pada Gambar 12 sebagai berikut,



Gambar 12. *Flowchart* satu dimensi bahan homogen.

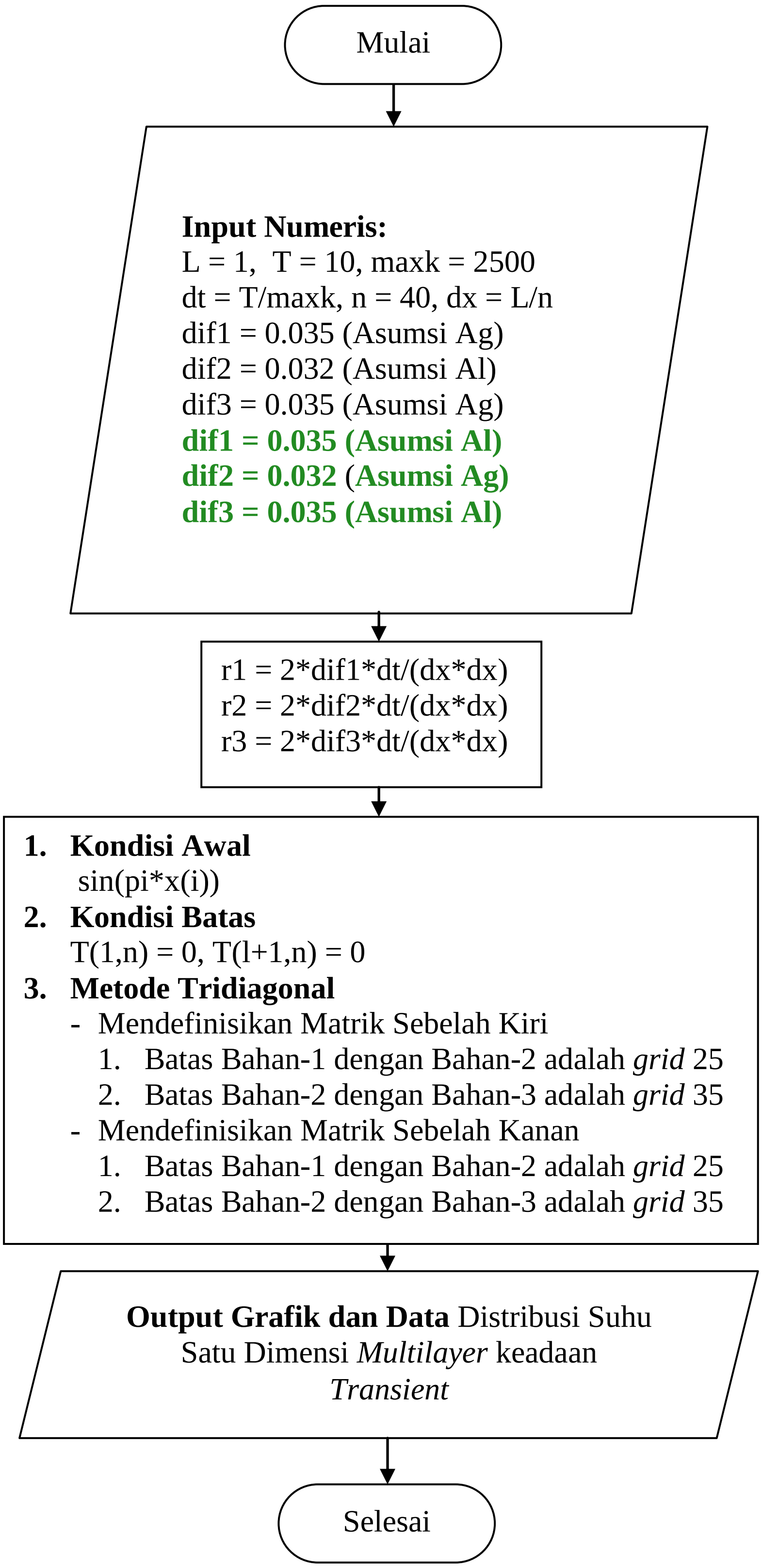
a. Satu Dimensi Bahan *Multilayer* Keadaan *Transient*

Bentuk model satu dimensi bahan *multilayer* yang digunakan seperti pada Gambar 13.



Gambar 13. Model satu dimensi bahan *multilayer*.

Persamaan satu dimensi bahan homogen yang digunakan pada penelitian ini menggunakan skema Eksplisit, dapat dilihat pada Persamaan (81) pada batas *layer*1 dan 2, Persamaan (86) pada batas *layer* 2 dan 3 dengan suhu awal $T(i,1) = sin(\pi x)$, syarat batas *dirichlet* bernilai 0 pada kedua ujung bahan, panjang sumbu-*x* adalah 1 dengan *grid*, batas *layer*1 dan *layer* 2 pada *grid* 25 dan batas *layer* 2 dan *layer* 3 adalah pada *grid* 35 sedangkan panjang temperatur 10 dengan asumsi bahan yang dimodelkan adalah Aluminium dan Perak dengan difusivitas bahan keduanya adalah 0,032 dan 0,035. Model *layer* 1,2 dan 3 berturut-turut adalah Aluminium-Perak-Aluminium dan Perak-Aluminium-Perak, *flowchart* visualisasi distribusi suhu satu dimensi pada bahan *multilayer* ini dapat di lihat pada Gambar 14 sebagai berikut,

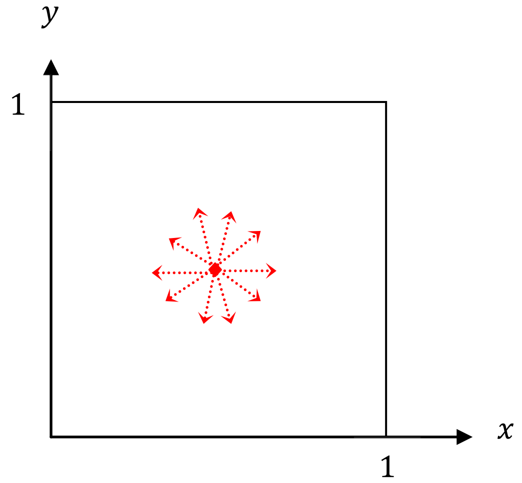


Gambar 14. *Flowchart* satu dimensi bahan *multilayer*.

2. Penyusunan Model Dua Dimensi Bahan Homogen Keadaan *Transient* dan Bahan Sembarang Keadaan *Steady State*

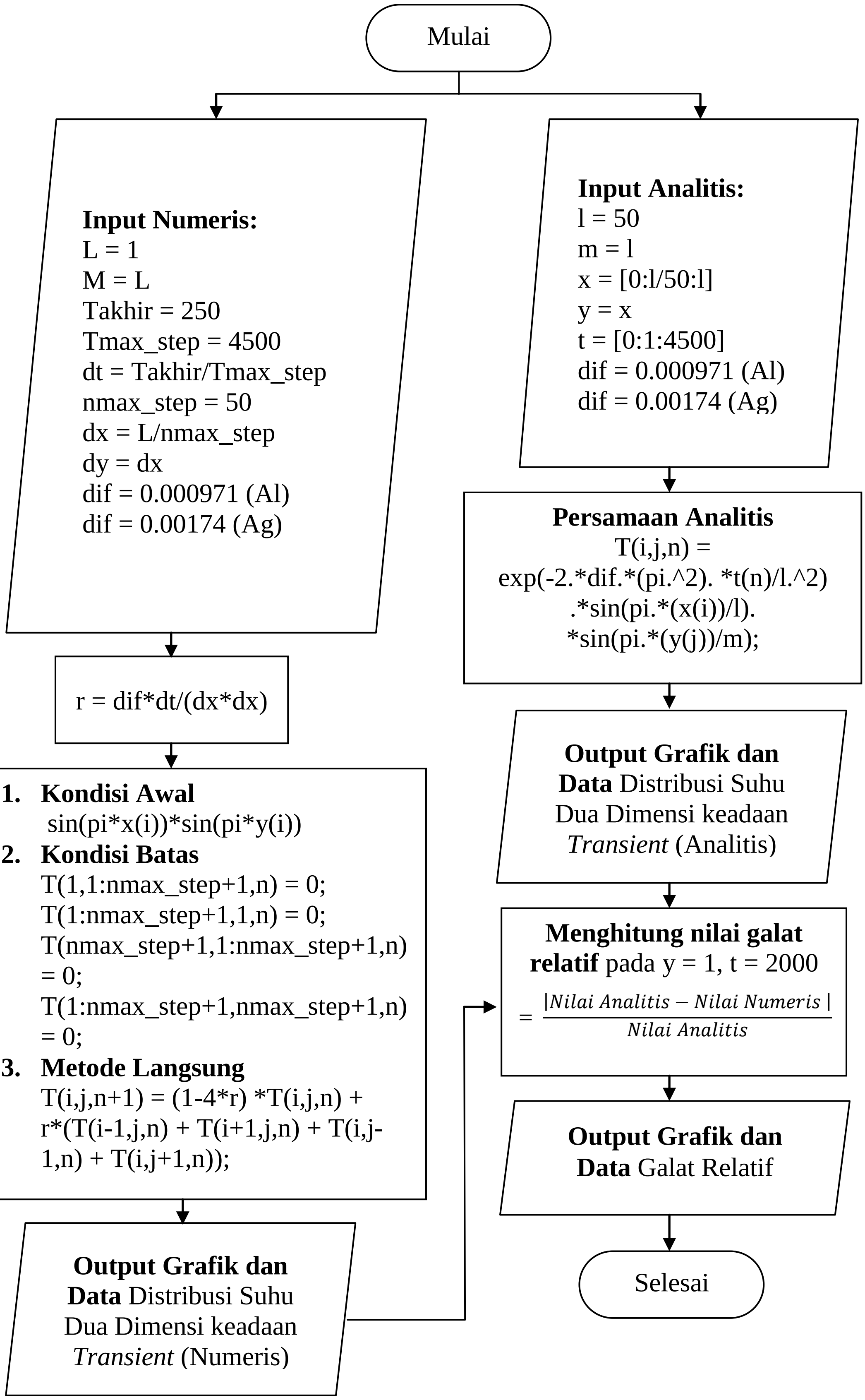
a. Dua Dimensi Bahan Homogen Keadaan *Transient*

Bentuk model dua dimensi bahan homogen yang digunakan seperti pada Gambar 15.



Gambar 15. Model dua dimensi bahan homogen.

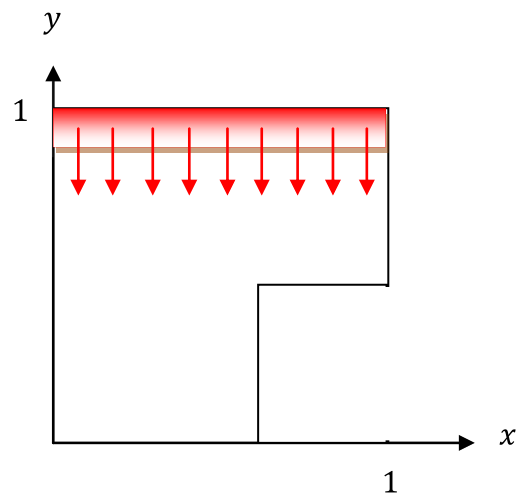
Persamaan dua dimensi bahan homogen yang digunakan pada penelitian ini menggunakan skema Eksplisit, penyelesainnya menggunakan Persamaan (45) sedangkan persamaan analitis menggunakan Persamaan (71). Keduanya dengan menerapkan suhu awal $T(i,j,1) = sin(\pi x)\, sin(\pi y)$, syarat batas *dirichlet* bernilai 0 pada kedua ujung sumbu-*x* dan *y*, panjang sumbu-*x*,*y* adalah 1, bahan yang dimodelkan adalah Aluminium dan Perak dengan difusivitas bahan keduanya adalah 0,000971 dan 0,00174 dengan dan panjang temperatur 250 pada bahan Aluminium dan 118,75 pada bahan Perak., *flowchart* visualisasi distribusi suhu dua dimensi pada bahan homogen ini dapat di lihat pada Gambar 16 sebagai berikut,



Gambar 16. *Flowchart* dua dimensi bahan Homogen.

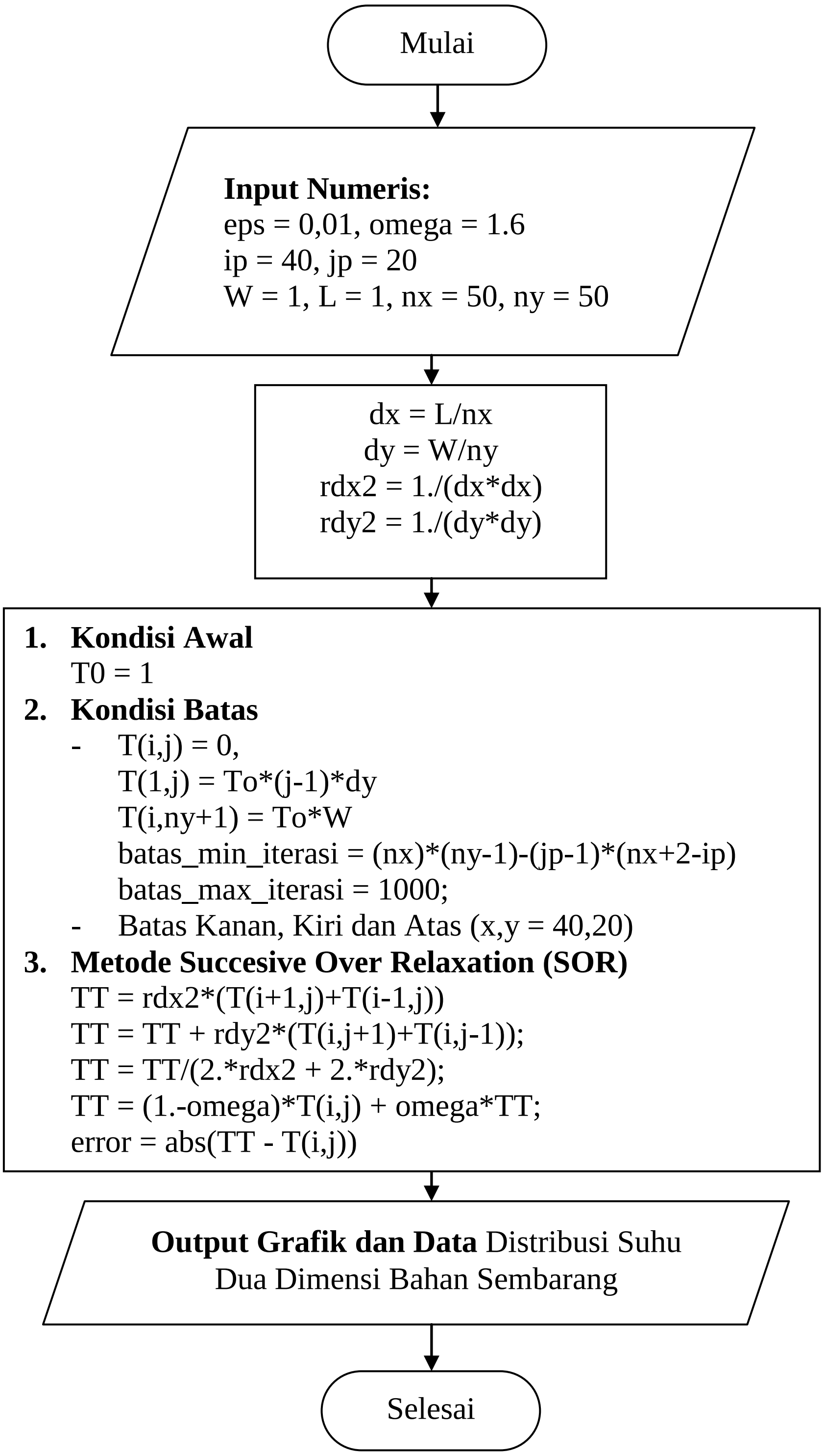
b. Dua Dimensi Bahan Sembarang Keadaan *Steady State*

Bentuk model dua dimensi bahan sembarang yang digunakan seperti pada gambar 17.



Gambar 17. Model dua dimensi bahan sembarang.

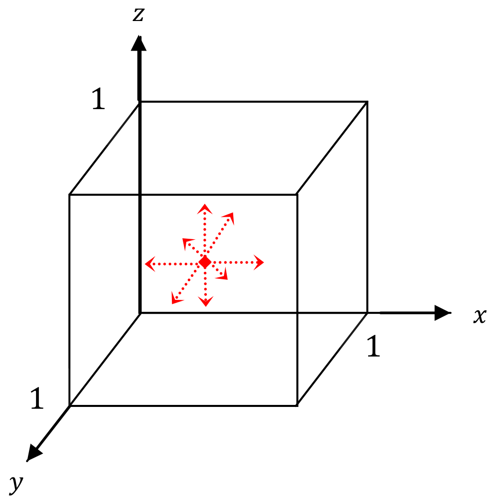
Persamaan dua dimensi bahan sembarang yang digunakan pada penelitian ini menggunakan metode SOR, penyelesainnya menggunakan persamaan (90) syarat batas *dirichlet* bernilai 0 pada batas sumbu-*x*dan *y* dengan $\omega = 1{,}6$, panjang sumbu-*x* adalah 1 *grid* 50 dengan batas sumbu-*x* 40 dan panjang sumbu-*y* adalah 1 *grid* 50 dengan batas 20. *flowchart* visualisasi distribusi suhu dua dimensi pada bahan sembarang ini dapat di lihat pada Gambar 18 sebagai berikut,



Gambar 18. *Flowchart* dua dimensi bahan sembarang.

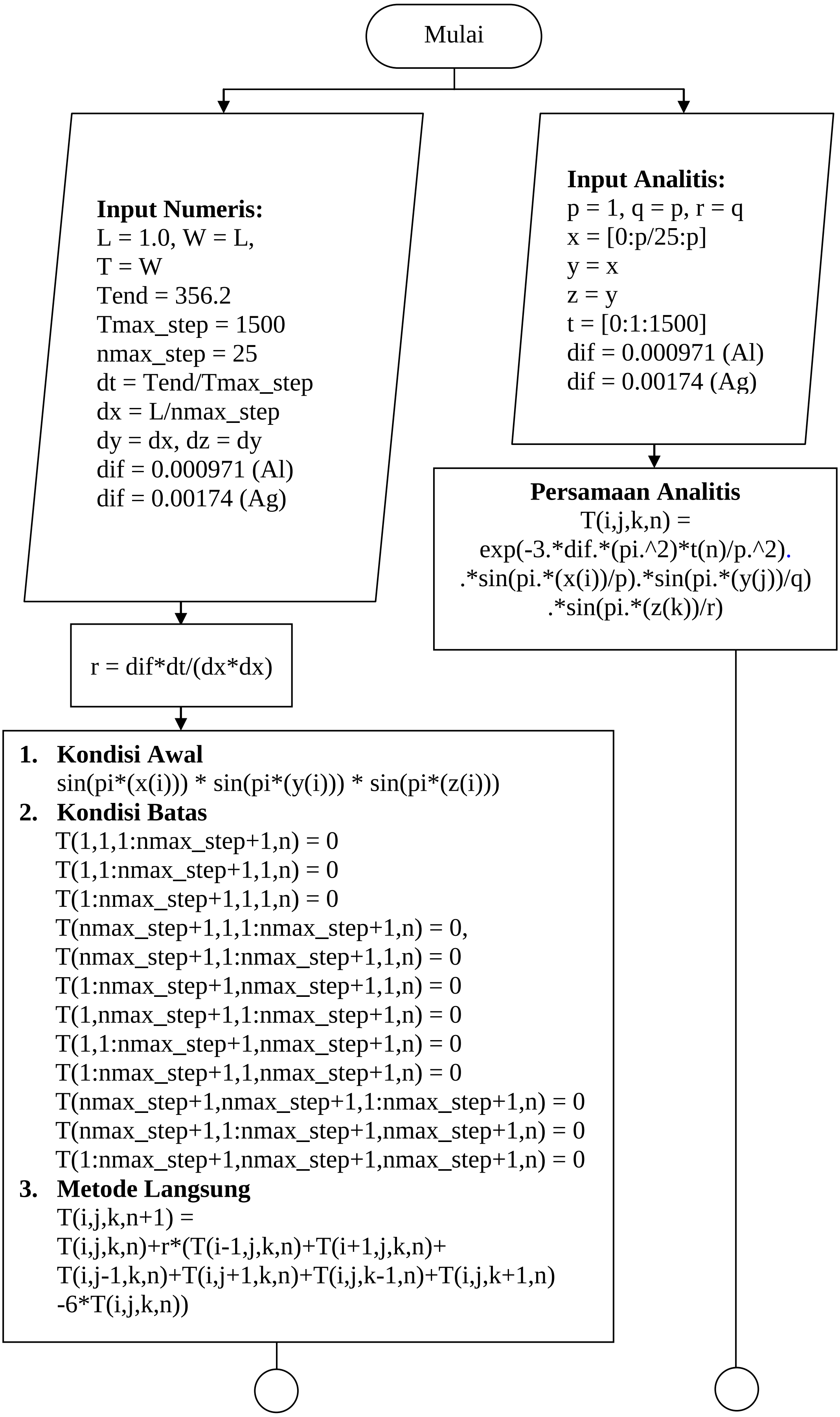
3. Penyusunan Model Tiga Dimensi Bahan Homogen Keadaan *Transient*

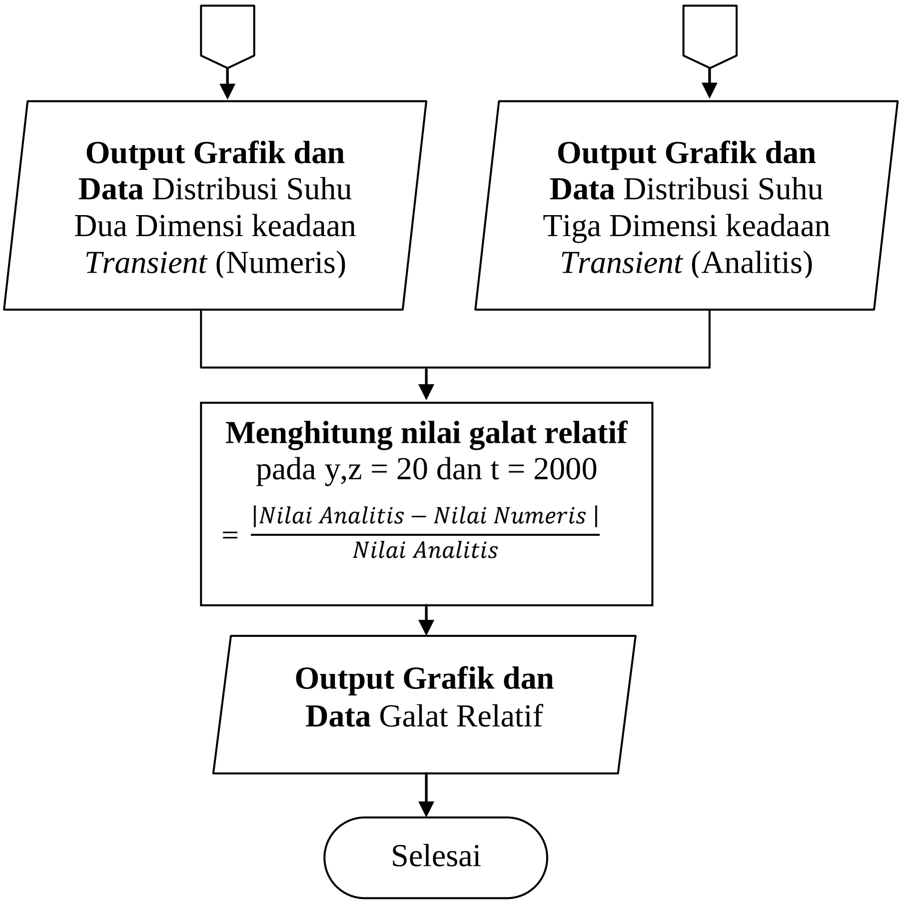
Bentuk model tiga dimensi bahan homogen yang digunakan seperti pada Gambar 19,



Gambar 19. Model tiga dimensi bahan homogen.

Persamaan tiga dimensi bahan homogen yang digunakan pada penelitian ini menggunakan skema Eksplisit, penyelesainnya menggunakan Persamaan (44) dan menggunakan Persamaan (72) pada penyelesaiain secara analitis, keduanya dengan menerapkan suhu awal $T(i, j, k, 1) = sin(\pi x)\, sin(\pi y)\, sin(\pi z)$, syarat batas *dirichlet* bernilai 0 pada kedua ujung sumbu-*x*, *y* dan *z*, panjang sumbu-*x*,*y*,*z* adalah 1, bahan yang dimodelkan adalah Aluminium dan Perak dengan difusivitas bahan keduanya adalah 0,000971 dan 0,00174 dengan dan panjang temperatur 356,2 pada bahan Aluminium dan 227,3 pada bahan Perak. *flowchart* visualisasi distribusi suhu dua dimensi pada bahan homogen ini dapat di lihat pada Gambar 20 sebagai berikut,


Mulai
Input Numeris:
L = 1.0, W = L,
T = W
Tend = 356.2
Tmax_step = 1500
nmax_step = 25
dt = Tend/Tmax_step
dx = L/nmax_step
dy = dx, dz = dy
dif = 0.000971 (Al)
dif = 0.00174 (Ag)
Input Analitis:
p = 1, q = p, r = q
x = [0:p/25:p]
y = x
z = y
t = [0:1:1500]
dif = 0.000971 (Al)
dif = 0.00174 (Ag)
Persamaan Analitis
T(i,j,k,n) =
exp(-3.*dif.*(pi.^2)*t(n)/p.^2).
.*sin(pi.*(x(i))/p).*sin(pi.*(y(j))/q)
.*sin(pi.*(z(k))/r)
r = dif*dt/(dx*dx)
1. Kondisi Awal
sin(pi*(x(i))) * sin(pi*(y(i))) * sin(pi*(z(i)))
2. Kondisi Batas
T(1,1,1:nmax_step+1,n) = 0
T(1,1:nmax_step+1,1,n) = 0
T(1:nmax_step+1,1,1,n) = 0
T(nmax_step+1,1,1:nmax_step+1,n) = 0,
T(nmax_step+1,1:nmax_step+1,1,n) = 0
T(1:nmax_step+1,nmax_step+1,1,n) = 0
T(1,nmax_step+1,1:nmax_step+1,n) = 0
T(1,1:nmax_step+1,nmax_step+1,n) = 0
T(1:nmax_step+1,1,nmax_step+1,n) = 0
T(nmax_step+1,nmax_step+1,1:nmax_step+1,n) = 0
T(nmax_step+1,1:nmax_step+1,nmax_step+1,n) = 0
T(1:nmax_step+1,nmax_step+1,nmax_step+1,n) = 0
3. Metode Langsung
T(i,j,k,n+1) =
T(i,j,k,n)+r*(T(i-1,j,k,n)+T(i+1,j,k,n)+
T(i,j-1,k,n)+T(i,j+1,k,n)+T(i,j,k-1,n)+T(i,j,k+1,n)
-6*T(i,j,k,n))



Gambar 20. *Flowchart* tiga dimensi bahan homogen.

BAB V

KESIMPULAN DAN SARAN

A. Kesimpulan

Kesimpulan yang didapat adalah sebagai berikut.

1. Distribusi suhu satu dimensi bahan homogen keadaan *transient* skema Crank-Nicolson memiliki akurasi yang baik dengan rata-rata nilai galat 0,000057 bahan Aluminium dan 0,0000562 pada bahan Perak pada x = 1 sampai dengan 50 dan waktu t 5.000.
2. Distribusi suhu satu dimensi bahan *multilayer* menggunakan skema eksplisit memiliki perubahan suhu pada lapisan *layer*. Bahan Aluminium-Perak-Aluminium memiliki distribusi yang lebih cepat dibandingkan bahan Perak-Aluminium-Perak.
3. Distribusi suhu dua dimensi bahan homogen skema Eksplisit bahan Aluminium memiliki galat awal 0,3592 hingga 0,4655 dan bahan Perak memiliki galat 0,3636 hingga 0,4804 pada x,y = 1 sampai dengan 50 dan waktu t 4.500 seiring bertambahnya *grid*.
4. Distribusi suhu dua dimensi bahan sembarang skema SOR keaadaan *steady state* sesuai dengan batas pada *grid* x,y = (40,20).
5. Distribusi suhu tiga dimensi bahan homogen skema eksplisit bahan Aluminium memiliki galat 1,901 hingga 1,895 dan bahan Perak 1,634

hingga 1,629 pada waktu *x* = 1 sampai dengan 25, *y*,*z* = 20 dan waktu *t* 500.

6. Distribusi suhu pada bahan Perak lebih cepat dibandingkan bahan Aluminium, semakin besar difusivitas maka distribusi suhu semakin cepat.

B. Saran

Saran yang dapat diberikan pada penelitian ini adalah sebagai berikut.

1. Menambah simulasi bahan keadaan *transient* maupun keadaan *setady state* sehingga didapatkan berbagai visualisasi distribusi suhu.
2. Memvisualisasikan bahan *multilayer* dua dimensi keadaan *transient.*
3. Memvisualisasikan distribusi suhu dengan metode selain Beda hingga.

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LAMPIRAN

Tabel 1. Hasil perhitungan distribusi temperatur pada kasus perpindahan panas satu dimensi dengan metode Crank-Nicolson (sumber: Sailah, 2010).

Waktu (t)	Temperatur										
	$x = 0$	$x = 0,1$	$x = 0,2$	$x = 0,3$	$x = 0,4$	$x = 0,5$	$x = 0,6$	$x = 0,7$	$x = 0,8$	$x = 0,9$	$x = 1$
$\mathbf{t} = 0$	0	0.3090	0.5878	0.8090	0.9511	1.0000	0.9511	0.8090	0.5878	0.3090	0
$\mathbf{t} = 0.05$	0	0.1875	0.3567	0.4909	0.5771	0.6068	0.5771	0.4909	0.3567	0.1875	0
$\mathbf{t} = 0.10$	0	0.1138	0.2164	0.2979	0.3502	0.3682	0.3502	0.2979	0.2164	0.1138	0
$\mathbf{t} = 0.15$	0	0.0690	0.1313	0.1807	0.2125	0.2234	0.2125	0.1807	0.1313	0.0690	0
$\mathbf{t} = 0.20$	0	0.0419	0.0797	0.1097	0.1289	0.1355	0.1289	0.1097	0.0797	0.0419	0
$\mathbf{t} = 0.25$	0	0.0254	0.0483	0.0665	0.0782	0.0822	0.0782	0.0665	0.0483	0.0254	0
$\mathbf{t} = 0.30$	0	0.0154	0.0293	0.0404	0.0475	0.0499	0.0475	0.0404	0.0293	0.0154	0

```matlab
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Distribusi suhu analitik 1 dimensi pada bahan Aluminium
% T(t,x) = exp(-pi^2*dif*t(i)/l^2)*sin(pi*x(j)/l)
% temperatur awal T0(x) = sin(pi*(x))
% Bahan Aluminium difusivitas 0.000971348 ~ 0.000971
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% inisialisasi parameter masukan

l = 50;                 % panjang x
x = [0:l/50:l];         % lebar grid x
t = [0:1:295000];       % waktu iterasi 0 sampai dengan 295000
dif = 0.000971;         % difusivitas bahan Aluminium
%T0 = sin(pi*x/50);     % temperatur awal

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menggunakan persamaan difusi 1 dimensi analtik

for n = 1:max(size(t))
    for i = 1:max(size(x))
    T(i,n)= exp(-pi^2*dif*t(n)/l^2).*sin(pi*x(i)/l);
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik difusi 1 dimensi analitik

%figure(1)
%plot(x,ci)         % menampilkan grafik temperatur awal

figure(1)
plot(x,T(:,1),'*',x,T(:,1000),'*',x,T(:,5000),'*',x,T(:,10000),'*',x,T(:,25000),...
    '*',x,T(:,100000),'*',x,T(:,295000),'*')
axis tight
a = legend('t = 1 ','t = 1000','t = 5000','t = 10000','t = 250000',...
    't = 100000','t = 295000');
set(a,'FontAngle','italic')
title 'Difusi Suhu Bahan Aluminium 1 Dimensi Analitik'
xlabel Sumbu-x
ylabel Temperatur

figure(2)
plot(t,T(1,:),'*',t,T(10,:),'*',t,T(20,:),'*',t,T(50,:),'*')
axis tight
b = legend('x = 0 atau x = l', 'x = 10', 'x = 20','x = 50');
set(b,'FontAngle','italic')
title 'Difusi Suhu Bahan Aluminium 1 Dimensi Analitik'
xlabel Waktu
ylabel Temperatur

figure(3)
mesh(x,t,T')
axis tight
title 'Difusi Suhu Bahan Aluminium 1 Dimensi Analitik'
xlabel Sumbu-x
ylabel Waktu
zlabel Temperatur

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,295000))     % menampilkan data pada t = 295000
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Aluminium 1 Dimensi
Analitik');
data = {x(1), T(1,1), T(1,1000), T(1,5000), T(1,10000), T(1,25000), T(1,100000),
T(1,295000);
        x(2), T(2,1), T(2,1000), T(2,5000), T(2,10000), T(2,25000), T(2,100000),
T(2,295000);
        x(3), T(3,1), T(3,1000), T(3,5000), T(3,10000), T(3,25000), T(3,100000),
T(3,295000);
        x(4), T(4,1), T(4,1000), T(4,5000), T(4,10000), T(4,25000), T(4,100000),
T(4,295000);
        x(5), T(5,1), T(5,1000), T(5,5000), T(5,10000), T(5,25000), T(5,100000),
T(5,295000);
        x(6), T(6,1), T(6,1000), T(6,5000), T(6,10000), T(6,25000), T(6,100000),
T(6,295000);
```

```
        x(7), T(7,1), T(7,1000), T(7,5000), T(7,10000), T(7,25000), T(7,100000),
T(7,295000);
        x(8), T(8,1), T(8,1000), T(8,5000), T(8,10000), T(8,25000), T(8,100000),
T(8,295000);
        x(9), T(9,1), T(9,1000), T(9,5000), T(9,10000), T(9,25000), T(9,100000),
T(9,295000);
        x(10), T(10,1), T(10,1000), T(10,5000), T(10,10000), T(10,25000), T(10,100000),
T(10,295000);
        x(11), T(11,1), T(11,1000), T(11,5000), T(11,10000), T(11,25000), T(11,100000),
T(11,295000);
        x(12), T(12,1), T(12,1000), T(12,5000), T(12,10000), T(12,25000), T(12,100000),
T(12,295000);
        x(13), T(13,1), T(13,1000), T(13,5000), T(13,10000), T(13,25000), T(13,100000),
T(13,295000);
        x(14), T(14,1), T(14,1000), T(14,5000), T(14,10000), T(14,25000), T(14,100000),
T(14,295000);
        x(15), T(15,1), T(15,1000), T(15,5000), T(15,10000), T(15,25000), T(15,100000),
T(15,295000);
        x(16), T(16,1), T(16,1000), T(16,5000), T(16,10000), T(16,25000), T(16,100000),
T(16,295000);
        x(17), T(17,1), T(17,1000), T(17,5000), T(17,10000), T(17,25000), T(17,100000),
T(17,295000);
        x(18), T(18,1), T(18,1000), T(18,5000), T(18,10000), T(18,25000), T(18,100000),
T(18,295000);
        x(19), T(19,1), T(19,1000), T(19,5000), T(19,10000), T(19,25000), T(19,100000),
T(19,295000);
        x(20), T(20,1), T(20,1000), T(20,5000), T(20,10000), T(20,25000), T(20,100000),
T(20,295000);
        x(21), T(21,1), T(21,1000), T(21,5000), T(21,10000), T(21,25000), T(21,100000),
T(21,295000);
        x(22), T(22,1), T(22,1000), T(22,5000), T(22,10000), T(22,25000), T(22,100000),
T(22,295000);
        x(23), T(23,1), T(23,1000), T(23,5000), T(23,10000), T(23,25000), T(23,100000),
T(23,295000);
        x(24), T(24,1), T(24,1000), T(24,5000), T(24,10000), T(24,25000), T(24,100000),
T(24,295000);
        x(25), T(25,1), T(25,1000), T(25,5000), T(25,10000), T(25,25000), T(25,100000),
T(25,295000);
        x(26), T(26,1), T(26,1000), T(26,5000), T(26,10000), T(26,25000), T(26,100000),
T(26,295000);
        x(27), T(27,1), T(27,1000), T(27,5000), T(27,10000), T(27,25000), T(27,100000),
T(27,295000);
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T(28,295000);
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T(29,295000);
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T(30,295000);
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T(31,295000);
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T(34,295000);
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T(35,295000);
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T(36,295000);
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T(37,295000);
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T(38,295000);
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T(40,295000);
        x(41), T(41,1), T(41,1000), T(41,5000), T(41,10000), T(41,25000), T(41,100000),
T(41,295000);
        x(42), T(42,1), T(42,1000), T(42,5000), T(42,10000), T(42,25000), T(42,100000),
T(42,295000);
        x(43), T(43,1), T(43,1000), T(43,5000), T(43,10000), T(42,25000), T(43,100000),
T(43,295000);
        x(44), T(44,1), T(44,1000), T(44,5000), T(44,10000), T(44,25000), T(44,100000),
T(44,295000);
        x(45), T(45,1), T(45,1000), T(45,5000), T(45,10000), T(45,25000), T(45,100000),
T(45,295000);
        x(46), T(46,1), T(46,1000), T(46,5000), T(46,10000), T(46,25000), T(46,100000),
T(46,295000);
        x(47), T(47,1), T(47,1000), T(47,5000), T(47,10000), T(47,25000), T(47,100000),
T(47,295000);
        x(48), T(48,1), T(48,1000), T(48,5000), T(48,10000), T(48,25000), T(48,100000),
T(48,295000);
```

```
        x(49), T(49,1), T(49,1000), T(49,5000), T(49,10000), T(49,25000), T(49,100000), 
T(49,295000);
        x(50), T(50,1), T(50,1000), T(50,5000), T(50,10000), T(50,25000), T(50,100000), 
T(50,295000);
        x(51), T(51,1), T(51,1000), T(51,5000), T(51,10000), T(51,25000), T(51,100000), 
T(51,295000);};

columnname = {'Sumbu-x','T(x,1)','T(x,1000)','T(x,5000)','T(x,10000)',...
    'T(x,25000)','T(x,100000)','T(x,295000)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long','long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Distribusi suhu analitik 1 dimensi pada bahan Perak
% T(t,x) = exp(-pi^2*alfa2*t(i)/l^2)*sin(pi*x(i)/l)
% temperatur awal T0(x) = sin(pi*(x))
% Bahan Perak difusivitas 0.173860182 ~ 0.00174
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% inisialisasi parameter masukan

l = 50;                 % panjang x
x = [0:l/50:l];         % lebar x
t = [0:1:295000];       % waktu iterasi 0 sampai dengan 295000
dif = 0.00174;          % difusivitas bahan Perak
%T0 = sin(pi*x/50);     % temperatur awal

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menggunakan persamaan difusi 1 dimensi analtik

for n = 1:max(size(t))
    for i = 1:max(size(x))
    T(i,n)= exp(-pi^2*dif*t(n)/l^2).*sin(pi*x(i)/l);
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik difusi 1 dimensi analitik

%figure(1)
%plot(x,T0)         % menampilkan grafik temperatur awal

figure(1)
plot(x,T(:,1),'*',x,T(:,1000),'*',x,T(:,5000),'*',x,T(:,10000),'*',x,T(:,25000),...
    '*',x,T(:,100000),'*',x,T(:,295000),'*')
axis tight
a = legend('t = 1','t = 1000','t = 5000','t = 10000','t = 250000',...
    't = 100000','t = 295000');
set(a,'FontAngle','italic')
title 'Difusi Suhu Bahan Perak 1 Dimensi Analitik'
xlabel Sumbu-x
ylabel Temperatur

figure(2)
plot(t,T(1,:),'*',t,T(10,:),'*',t,T(20,:),'*',t,T(50,:),'*')
axis tight
b = legend('x = 0 atau x = l', 'x = 10', 'x = 20','x = 50');
set(b,'FontAngle','italic')
title 'Difusi Suhu Bahan Perak 1 Dimensi Analitik'
xlabel Waktu
ylabel Temperatur

figure(3)
mesh(x,t,T')
axis tight
title 'Difusi Suhu Bahan Perak 1 Dimensi Analitik'
xlabel Sumbu-x
ylabel Waktu
zlabel Temperatur

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,12500))     % menampilkan data pada t = 12500
```

```
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Perak 1 Dimensi
Analitik');
data = {x(1), T(1,1), T(1,1000), T(1,5000), T(1,10000), T(1,25000), T(1,100000),
T(1,295000);
        x(2), T(2,1), T(2,1000), T(2,5000), T(2,10000), T(2,25000), T(2,100000),
T(2,295000);
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T(3,295000);
        x(4), T(4,1), T(4,1000), T(4,5000), T(4,10000), T(4,25000), T(4,100000),
T(4,295000);
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T(5,295000);
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T(9,295000);
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T(10,295000);
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T(11,295000);
        x(12), T(12,1), T(12,1000), T(12,5000), T(12,10000), T(12,25000), T(12,100000),
T(12,295000);
        x(13), T(13,1), T(13,1000), T(13,5000), T(13,10000), T(13,25000), T(13,100000),
T(13,295000);
        x(14), T(14,1), T(14,1000), T(14,5000), T(14,10000), T(14,25000), T(14,100000),
T(14,295000);
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T(15,295000);
        x(16), T(16,1), T(16,1000), T(16,5000), T(16,10000), T(16,25000), T(16,100000),
T(16,295000);
        x(17), T(17,1), T(17,1000), T(17,5000), T(17,10000), T(17,25000), T(17,100000),
T(17,295000);
        x(18), T(18,1), T(18,1000), T(18,5000), T(18,10000), T(18,25000), T(18,100000),
T(18,295000);
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T(19,295000);
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T(20,295000);
        x(21), T(21,1), T(21,1000), T(21,5000), T(21,10000), T(21,25000), T(21,100000),
T(21,295000);
        x(22), T(22,1), T(22,1000), T(22,5000), T(22,10000), T(22,25000), T(22,100000),
T(22,295000);
        x(23), T(23,1), T(23,1000), T(23,5000), T(23,10000), T(23,25000), T(23,100000),
T(23,295000);
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T(25,295000);
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T(26,295000);
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T(27,295000);
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T(28,295000);
        x(29), T(29,1), T(29,1000), T(29,5000), T(29,10000), T(29,25000), T(29,100000),
T(29,295000);
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T(30,295000);
        x(31), T(31,1), T(31,1000), T(31,5000), T(31,10000), T(31,25000), T(31,100000),
T(31,295000);
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T(32,295000);
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T(33,295000);
        x(34), T(34,1), T(34,1000), T(34,5000), T(34,10000), T(34,25000), T(34,100000),
T(34,295000);
        x(35), T(35,1), T(35,1000), T(35,5000), T(35,10000), T(35,25000), T(35,100000),
T(35,295000);
        x(36), T(36,1), T(36,1000), T(36,5000), T(36,10000), T(36,25000), T(36,100000),
T(36,295000);
        x(37), T(37,1), T(37,1000), T(37,5000), T(37,10000), T(37,25000), T(37,100000),
T(37,295000);
        x(38), T(38,1), T(38,1000), T(38,5000), T(38,10000), T(38,25000), T(38,100000),
T(38,295000);
        x(39), T(39,1), T(39,1000), T(39,5000), T(39,10000), T(39,25000), T(39,100000),
T(39,295000);
        x(40), T(40,1), T(40,1000), T(40,5000), T(40,10000), T(40,25000), T(40,100000),
T(40,295000);
        x(41), T(41,1), T(41,1000), T(41,5000), T(41,10000), T(41,25000), T(41,100000),
T(41,295000);
```

```
        x(42), T(42,1), T(42,1000), T(42,5000), T(42,10000), T(42,25000), T(42,100000),
T(42,295000);
        x(43), T(43,1), T(43,1000), T(43,5000), T(43,10000), T(42,25000), T(43,100000),
T(43,295000);
        x(44), T(44,1), T(44,1000), T(44,5000), T(44,10000), T(44,25000), T(44,100000),
T(44,295000);
        x(45), T(45,1), T(45,1000), T(45,5000), T(45,10000), T(45,25000), T(45,100000),
T(45,295000);
        x(46), T(46,1), T(46,1000), T(46,5000), T(46,10000), T(46,25000), T(46,100000),
T(46,295000);
        x(47), T(47,1), T(47,1000), T(47,5000), T(47,10000), T(47,25000), T(47,100000),
T(47,295000);
        x(48), T(48,1), T(48,1000), T(48,5000), T(48,10000), T(48,25000), T(48,100000),
T(48,295000);
        x(49), T(49,1), T(49,1000), T(49,5000), T(49,10000), T(49,25000), T(49,100000),
T(49,295000);
        x(50), T(50,1), T(50,1000), T(50,5000), T(50,10000), T(50,25000), T(50,100000),
T(50,295000);
        x(51), T(51,1), T(51,1000), T(51,5000), T(51,10000), T(51,25000), T(51,100000),
T(51,295000);};

columnname = {'Sumbu-x','T(x,1)','T(x,1000)','T(x,5000)','T(x,10000)',...
    'T(x,25000)','T(x,100000)','T(x,295000)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long','long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Distribusi suhu numerik 1 dimensi pada bahan Aluminium
% Menggunakan metode Crank-Nicolson
% Keadaan ini stabil pada r <= 1/2 dan dt <= dx^2/2
% Bahan Aluminium difusivitas 0.000971348 ~ 0.000971
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Inisialisasi parameter masukan

L = 1;                          % panjang x
Temp = 120.;                    % panjang temperatur
maxk = 295000.;                 % grid temperatur 295000
dt = Temp/maxk;                 % delta t
l = 50.;                        % banyaknya ruang step x
dx = L/l;                       % delta x

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% sifat fisis bahan

% kond = 237;                       % konduktivitas bahan
% Cp = 903;                         % panas spesifik bahan
% rho = 2702.;                      % massa jenis bahan
dif = 0.000971;                     % difusivitas = cond/(spheat*rho);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% parameter masukan nilai r

r = dif*dt/(dx*dx);             % r = 0,00181875
% r = dif*dt/(dx*dx*2)          % r menggunakan metode Crank-Nicolson 1

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Kondisi awal
% temperatur awal pada kawat adalah sinus(pi*x(i)

for i = 1:l+1
    x(i) = (i-1)*dx;
    T(i,1) = sin(pi*x(i));
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Kondisi batas
% Temperatur batas (T=0)

for n = 1:maxk+1
    T(1,n) = 0;
    T(l+1,n) = 0;
    t(n) = (n-1)*dt;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```matlab
% Implementasi metode Crank-Nicholson 1

% for n = 1:maxk
%    for i = 2:n
%        T(i,n+1) = ((2-2*r)*T(i,n)+b*(T(i+1,n)+T(i-1,n))...
%            +r*(T(i+1,n+1)+T(i-1,n+1)))/(2+2*r);
%   end
% end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Selain menggunakan metode Crank-Nicolson 1 secara langsung, dapat
% digunakan metode lain untuk memecahkan metode Crank-Nicolson yaitu dengan
% menggunakan metode dekomposisi LU,
% dibawah ini penulis menggunakan metode tridiagonal
% Mendifinisikan matrik pada sebelah kiri dan sebelah kanan
%
aal(1:l-2) = -r;
bbl(1:l-1) = 2+2*r;
ccl(1:l-2) = -r;
MMl = diag(bbl,0)+diag(aal,-1)+diag(ccl,1);

aar(1:l-2) = r;
bbr(1:l-1) = 2-2*r;
ccr(1:l-2) = r;
MMr = diag(bbr,0)+diag(aar,-1)+diag(ccr,1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Implementasi pada persamaan Crank-Nicolson 2

for n = 2:maxk
    TT = T(2:l,n-1);
    T(2:l,n) = inv(MMl)*MMr*TT;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan grafik difusi 1 dimensi numerik

figure(1)
plot(x,T(:,1),'*',x,T(:,1000),'*',x,T(:,5000),'*',x,T(:,10000),'*',x,T(:,25000),...
    '*',x,T(:,100000),'*',x,T(:,295000),'*')
axis tight
a = legend('t = 1','t = 1000','t = 5000','t = 10000','t = 250000',...
    't = 100000','t = 295000');
set(a,'FontAngle','italic')
title 'Difusi Suhu Bahan Aluminium 1 Dimensi Metode Crank-Nicolson'
xlabel Sumbu-x
ylabel Temperatur

figure(2)
plot(t,T(1,:),'*',t,T(10,:),'*',t,T(20,:),'*',t,T(50,:),'*')
axis tight
b = legend('x = 0 atau x = l', 'x = 10', 'x = 20','x = 50');
set(b,'FontAngle','italic')
title 'Difusi Suhu Bahan Aluminium 1 Dimensi Metode Crank-Nicolson'
xlabel Waktu
ylabel Temperatur

figure(3)
mesh(x,t,T')
axis tight
title 'Difusi Suhu Bahan Aluminium 1 Dimensi Metode Crank-Nicolson'
xlabel Sumbu-x
ylabel Waktu
zlabel Temperatur

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,12500))     % menampilkan data pada t = 12500
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Aluminium 1 Dimensi
Metode Crank-Nicolson');
data = {x(1), T(1,1), T(1,1000), T(1,5000), T(1,10000), T(1,25000), T(1,100000),
T(1,295000);
        x(2), T(2,1), T(2,1000), T(2,5000), T(2,10000), T(2,25000), T(2,100000),
T(2,295000);
        x(3), T(3,1), T(3,1000), T(3,5000), T(3,10000), T(3,25000), T(3,100000),
T(3,295000);
        x(4), T(4,1), T(4,1000), T(4,5000), T(4,10000), T(4,25000), T(4,100000),
T(4,295000);
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T(5,295000);
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T(6,295000);
```

```
        x(7), T(7,1), T(7,1000), T(7,5000), T(7,10000), T(7,25000), T(7,100000),
T(7,295000);
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T(8,295000);
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T(9,295000);
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        x(11), T(11,1), T(11,1000), T(11,5000), T(11,10000), T(11,25000), T(11,100000),
T(11,295000);
        x(12), T(12,1), T(12,1000), T(12,5000), T(12,10000), T(12,25000), T(12,100000),
T(12,295000);
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T(23,295000);
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T(24,295000);
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T(25,295000);
        x(26), T(26,1), T(26,1000), T(26,5000), T(26,10000), T(26,25000), T(26,100000),
T(26,295000);
        x(27), T(27,1), T(27,1000), T(27,5000), T(27,10000), T(27,25000), T(27,100000),
T(27,295000);
        x(28), T(28,1), T(28,1000), T(28,5000), T(28,10000), T(28,25000), T(28,100000),
T(28,295000);
        x(29), T(29,1), T(29,1000), T(29,5000), T(29,10000), T(29,25000), T(29,100000),
T(29,295000);
        x(30), T(30,1), T(30,1000), T(30,5000), T(30,10000), T(30,25000), T(30,100000),
T(30,295000);
        x(31), T(31,1), T(31,1000), T(31,5000), T(31,10000), T(31,25000), T(31,100000),
T(31,295000);
        x(32), T(32,1), T(32,1000), T(32,5000), T(32,10000), T(32,25000), T(32,100000),
T(32,295000);
        x(33), T(33,1), T(33,1000), T(33,5000), T(33,10000), T(33,25000), T(33,100000),
T(33,295000);
        x(34), T(34,1), T(34,1000), T(34,5000), T(34,10000), T(34,25000), T(34,100000),
T(34,295000);
        x(35), T(35,1), T(35,1000), T(35,5000), T(35,10000), T(35,25000), T(35,100000),
T(35,295000);
        x(36), T(36,1), T(36,1000), T(36,5000), T(36,10000), T(36,25000), T(36,100000),
T(36,295000);
        x(37), T(37,1), T(37,1000), T(37,5000), T(37,10000), T(37,25000), T(37,100000),
T(37,295000);
        x(38), T(38,1), T(38,1000), T(38,5000), T(38,10000), T(38,25000), T(38,100000),
T(38,295000);
        x(39), T(39,1), T(39,1000), T(39,5000), T(39,10000), T(39,25000), T(39,100000),
T(39,295000);
        x(40), T(40,1), T(40,1000), T(40,5000), T(40,10000), T(40,25000), T(40,100000),
T(40,295000);
        x(41), T(41,1), T(41,1000), T(41,5000), T(41,10000), T(41,25000), T(41,100000),
T(41,295000);
        x(42), T(42,1), T(42,1000), T(42,5000), T(42,10000), T(42,25000), T(42,100000),
T(42,295000);
        x(43), T(43,1), T(43,1000), T(43,5000), T(43,10000), T(42,25000), T(43,100000),
T(43,295000);
        x(44), T(44,1), T(44,1000), T(44,5000), T(44,10000), T(44,25000), T(44,100000),
T(44,295000);
        x(45), T(45,1), T(45,1000), T(45,5000), T(45,10000), T(45,25000), T(45,100000),
T(45,295000);
        x(46), T(46,1), T(46,1000), T(46,5000), T(46,10000), T(46,25000), T(46,100000),
T(46,295000);
        x(47), T(47,1), T(47,1000), T(47,5000), T(47,10000), T(47,25000), T(47,100000),
T(47,295000);
        x(48), T(48,1), T(48,1000), T(48,5000), T(48,10000), T(48,25000), T(48,100000),
T(48,295000);
```

```
        x(49), T(49,1), T(49,1000), T(49,5000), T(49,10000), T(49,25000), T(49,100000),
T(49,295000);
        x(50), T(50,1), T(50,1000), T(50,5000), T(50,10000), T(50,25000), T(50,100000),
T(50,295000);
        x(51), T(51,1), T(51,1000), T(51,5000), T(51,10000), T(51,25000), T(51,100000),
T(51,295000);};

columnname = {'Sumbu-x','T(x,1)','T(x,1000)','T(x,5000)','T(x,10000)',...
    'T(x,25000)','T(x,100000)','T(x,295000)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long','long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Distribusi suhu numerik 1 dimensi pada bahan Perak
% Metode ini menggunakan metode Crank-Nicolson
% Keadaan ini stabil pada r <= 1/2 dan dt <= dx^2/2
% Bahan Perak difusivitas 0.00173860182 ~ 0.00174
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% inisialisasi parameter masukan

L = 1;                          % panjang x
Temp = 120;                     % panjang temperatur
maxk = 295000.;                 % grid temperatur 295000
dt = Temp/maxk;                 % delta t
l = 50;                         % banyaknya ruang step x
dx = L/l;                       % delta x

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% sifat fisis bahan

% kond = 429.;                  % konduktivitas bahan
% Cp = 235.;                    % panas spesifik
% rho = 10500.;                 % massa jenis bahan
dif = 0.00174;                  % difusivitas = cond/(spheat*rho);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% parameter masukan nilai r

r = dif*dt/(dx*dx);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Kondisi awal
% temperatur awal pada kawat adalah sinus(pi*x(i)

for i = 1:l+1
    x(i) = (i-1)*dx;
    T(i,1) = sin(pi*x(i));
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Kondisi batas
% Temperatur batas (T=0)

for n = 1:maxk+1
    T(1,n) = 0;
    T(l+1,n) = 0;
    t(n) = (n-1)*dt;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Implementasi metode Crank-Nicholson
% for n = 1:maxk
%     for i = 2:l
%         T(i,n+1) = ((2-2*r)*T(i,n)+r*(T(i+1,n)+T(i-1,n))...
%             +r*(T(i+1,n+1)+T(i-1,n+1)))/(2+2*r);
%    end
% end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Mendifinisikan matrik pada sebelah kiri dan sebelah kanan

aal(1:l-2) = -r;
bbl(1:l-1) = 2+2*r;
ccl(1:l-2) = -r;
MMl = diag(bbl,0)+diag(aal,-1)+diag(ccl,1);

aar(1:l-2) = r;
bbr(1:l-1) = 2-2*r;
ccr(1:l-2) = r;
MMr = diag(bbr,0)+diag(aar,-1)+diag(ccr,1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Implementasi pada persamaan Crank-Nicolson

for n = 2:maxk
    TT = T(2:l,n-1);
```

```
    T(2:l,n) = inv(MMl)*MMr*TT;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan grafik difusi 1 dimensi numerik

figure(1)
plot(x,T(:,1),'*',x,T(:,1000),'*',x,T(:,5000),'*',x,T(:,10000),'*',x,T(:,25000),...
    '*',x,T(:,100000),'*',x,T(:,295000),'*')
axis tight
a = legend('t = 1','t = 1000','t = 5000','t = 10000','t = 250000',...
    't = 100000','t = 295000');
set(a,'FontAngle','italic')
title 'Difusi Suhu Bahan Perak 1 Dimensi Metode Crank-Nicolson'
xlabel Sumbu-x
ylabel Temperatur

figure(2)
plot(t,T(1,:),'*',t,T(10,:),'*',t,T(20,:),'*',t,T(50,:),'*')
axis tight
b = legend('x = 0 atau x = l', 'x = 10', 'x = 20','x = 50');
set(b,'FontAngle','italic')
title 'Difusi Suhu Bahan Perak 1 Dimensi Metode Crank-Nicolson'
xlabel Waktu
ylabel Temperatur

figure(3)
mesh(x,t,T')
axis tight
title 'Difusi Suhu Bahan Perak 1 Dimensi Metode Crank-Nicolson'
xlabel Sumbu-x
ylabel Waktu
zlabel Temperatur

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,12500))     % menampilkan data pada t = 12500
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Perak 1 Dimensi Metode Crank-
Nicolson');
data = {x(1), T(1,1), T(1,1000), T(1,5000), T(1,10000), T(1,25000), T(1,100000), T(1,295000);
        x(2), T(2,1), T(2,1000), T(2,5000), T(2,10000), T(2,25000), T(2,100000), T(2,295000);
        x(3), T(3,1), T(3,1000), T(3,5000), T(3,10000), T(3,25000), T(3,100000), T(3,295000);
        x(4), T(4,1), T(4,1000), T(4,5000), T(4,10000), T(4,25000), T(4,100000), T(4,295000);
        x(5), T(5,1), T(5,1000), T(5,5000), T(5,10000), T(5,25000), T(5,100000), T(5,295000);
        x(6), T(6,1), T(6,1000), T(6,5000), T(6,10000), T(6,25000), T(6,100000), T(6,295000);
        x(7), T(7,1), T(7,1000), T(7,5000), T(7,10000), T(7,25000), T(7,100000), T(7,295000);
        x(8), T(8,1), T(8,1000), T(8,5000), T(8,10000), T(8,25000), T(8,100000), T(8,295000);
        x(9), T(9,1), T(9,1000), T(9,5000), T(9,10000), T(9,25000), T(9,100000), T(9,295000);
        x(10), T(10,1), T(10,1000), T(10,5000), T(10,10000), T(10,25000), T(10,100000), T(10,295000);
        x(11), T(11,1), T(11,1000), T(11,5000), T(11,10000), T(11,25000), T(11,100000), T(11,295000);
        x(12), T(12,1), T(12,1000), T(12,5000), T(12,10000), T(12,25000), T(12,100000), T(12,295000);
        x(13), T(13,1), T(13,1000), T(13,5000), T(13,10000), T(13,25000), T(13,100000), T(13,295000);
        x(14), T(14,1), T(14,1000), T(14,5000), T(14,10000), T(14,25000), T(14,100000), T(14,295000);
        x(15), T(15,1), T(15,1000), T(15,5000), T(15,10000), T(15,25000), T(15,100000), T(15,295000);
        x(16), T(16,1), T(16,1000), T(16,5000), T(16,10000), T(16,25000), T(16,100000), T(16,295000);
        x(17), T(17,1), T(17,1000), T(17,5000), T(17,10000), T(17,25000), T(17,100000), T(17,295000);
        x(18), T(18,1), T(18,1000), T(18,5000), T(18,10000), T(18,25000), T(18,100000), T(18,295000);
        x(19), T(19,1), T(19,1000), T(19,5000), T(19,10000), T(19,25000), T(19,100000), T(19,295000);
        x(20), T(20,1), T(20,1000), T(20,5000), T(20,10000), T(20,25000), T(20,100000), T(20,295000);
        x(21), T(21,1), T(21,1000), T(21,5000), T(21,10000), T(21,25000), T(21,100000), T(21,295000);
        x(22), T(22,1), T(22,1000), T(22,5000), T(22,10000), T(22,25000), T(22,100000), T(22,295000);
        x(23), T(23,1), T(23,1000), T(23,5000), T(23,10000), T(23,25000), T(23,100000), T(23,295000);
        x(24), T(24,1), T(24,1000), T(24,5000), T(24,10000), T(24,25000), T(24,100000), T(24,295000);
        x(25), T(25,1), T(25,1000), T(25,5000), T(25,10000), T(25,25000), T(25,100000), T(25,295000);
        x(26), T(26,1), T(26,1000), T(26,5000), T(26,10000), T(26,25000), T(26,100000), T(26,295000);
        x(27), T(27,1), T(27,1000), T(27,5000), T(27,10000), T(27,25000), T(27,100000), T(27,295000);
        x(28), T(28,1), T(28,1000), T(28,5000), T(28,10000), T(28,25000), T(28,100000), T(28,295000);
        x(29), T(29,1), T(29,1000), T(29,5000), T(29,10000), T(29,25000), T(29,100000), T(29,295000);
        x(30), T(30,1), T(30,1000), T(30,5000), T(30,10000), T(30,25000), T(30,100000), T(30,295000);
        x(31), T(31,1), T(31,1000), T(31,5000), T(31,10000), T(31,25000), T(31,100000), T(31,295000);
        x(32), T(32,1), T(32,1000), T(32,5000), T(32,10000), T(32,25000), T(32,100000), T(32,295000);
        x(33), T(33,1), T(33,1000), T(33,5000), T(33,10000), T(33,25000), T(33,100000), T(33,295000);
        x(34), T(34,1), T(34,1000), T(34,5000), T(34,10000), T(34,25000), T(34,100000), T(34,295000);
        x(35), T(35,1), T(35,1000), T(35,5000), T(35,10000), T(35,25000), T(35,100000), T(35,295000);
        x(36), T(36,1), T(36,1000), T(36,5000), T(36,10000), T(36,25000), T(36,100000), T(36,295000);
        x(37), T(37,1), T(37,1000), T(37,5000), T(37,10000), T(37,25000), T(37,100000), T(37,295000);
        x(38), T(38,1), T(38,1000), T(38,5000), T(38,10000), T(38,25000), T(38,100000), T(38,295000);
        x(39), T(39,1), T(39,1000), T(39,5000), T(39,10000), T(39,25000), T(39,100000), T(39,295000);
        x(40), T(40,1), T(40,1000), T(40,5000), T(40,10000), T(40,25000), T(40,100000), T(40,295000);
        x(41), T(41,1), T(41,1000), T(41,5000), T(41,10000), T(41,25000), T(41,100000), T(41,295000);
        x(42), T(42,1), T(42,1000), T(42,5000), T(42,10000), T(42,25000), T(42,100000), T(42,295000);
        x(43), T(43,1), T(43,1000), T(43,5000), T(43,10000), T(42,25000), T(43,100000), T(43,295000);
        x(44), T(44,1), T(44,1000), T(44,5000), T(44,10000), T(44,25000), T(44,100000), T(44,295000);
        x(45), T(45,1), T(45,1000), T(45,5000), T(45,10000), T(45,25000), T(45,100000), T(45,295000);
        x(46), T(46,1), T(46,1000), T(46,5000), T(46,10000), T(46,25000), T(46,100000), T(46,295000);
        x(47), T(47,1), T(47,1000), T(47,5000), T(47,10000), T(47,25000), T(47,100000), T(47,295000);
        x(48), T(48,1), T(48,1000), T(48,5000), T(48,10000), T(48,25000), T(48,100000), T(48,295000);
        x(49), T(49,1), T(49,1000), T(49,5000), T(49,10000), T(49,25000), T(49,100000), T(49,295000);
        x(50), T(50,1), T(50,1000), T(50,5000), T(50,10000), T(50,25000), T(50,100000), T(50,295000);
        x(51), T(51,1), T(51,1000), T(51,5000), T(51,10000), T(51,25000), T(51,100000), T(51,295000);};

columnname = {'Sumbu-x','T(x,1)','T(x,1000)','T(x,5000)','T(x,10000)',...
    'T(x,25000)','T(x,100000)','T(x,295000)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long','long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
```

```
            'ColumnFormat', columnformat,'RowName',[]);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Difusi analitik 1 dimensi bahan multilayer
% Metode ini menggunakan metode beda hingga
% Skema yang digunakan adalah skema Eksplisit (FTCS)
% Kondisi awal T0 = sin(pi*(x))
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Inisialisasi parameter masukan

L = 1;                        % panjang kawat
T = 10;                       % waktu akhir

% Parameter persamaan
maxk = 2500;                  % time step
dt = T/maxk;
n = 40;                       % jarak step
dx = L/n;
dif1 = 0.032;                 % difusivitas bahan Aluminium 0.000097
dif2 = 0.035;                 % difusivitas bahan Perak 0.000174
dif3 = 0.032;                 % difusivitas bahan Aluminium 0.000097
%dif1 = 0.035;                % difusivitas bahan Aluminium 0.000174
%dif2 = 0.032;                % difusivitas bahan Perak 0.000097
%dif3 = 0.035;                % difusivitas bahan Aluminium 0.000174
r1 = 2*dif1*dt/(dx*dx);       % stabilitas parameter (r1 = <1)
r2 = 2*dif2*dt/(dx*dx);       % stabilitas parameter (r2 = <1)
r3 = 2*dif3*dt/(dx*dx);       % stabilitas parameter (r3 = <1)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Kondisi awal
% temperatur awal pada kawat adalah sinus(pi*x(i)

for i = 1:n+1
    x(i) = (i-1)*dx;
    T(i,1) = sin(pi*x(i));
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Kondisi batas
% Temperatur batas (T=0)

for k = 1:maxk+1
    T(1,k) = 0;
    T(n+1,k) = 0;
    time(k) = (k-1)*dt;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Mendifinisikan matrik pada sebelah kiri dan sebelah kanan

aa(1:n-16) = r1;                 % 40-16 = 24
aa(n-15) = r1;                   % perbatasan layer 1 dan 2
aa(n-14:n-6) = r2;
aa(n-5) = r2;                    % perbatasan layer 2 dan 3
aa(n-4:n-2) = r3;

bb(1:n-16) = 1-2*r1;
bb(n-15) = 1-(r1+r2);            % perbatasan layer 1 dan 2
bb(n-14:n-6) = 1-2*r2;
bb(n-5) = 1-(r2+r3);             % perbatasan layer 2 dan 3
bb(n-4:n-1) = 1-2*r3;

cc(1:n-16) = r1; % 25-2 = 23
cc(n-15) = r2;                   % perbatasan layer 1 dan 2
cc(n-14:n-6) = r2;
cc(n-5) = r3;                    % perbatasan layer 2 dan 3
cc(n-4:n-2) = r3;

MM = diag(bb,0)+diag(aa,-1)+diag(cc,1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Implementasi metode Eksplisit

for k = 2:maxk;
    TT = T(2:n,k-1);
    T(2:n,k) = MM*TT;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan grafik difusi 1 dimensi numerik multilayer

figure(1)
axis tight
plot(x,T(:,1),'-',x,T(:,250),'-',x,T(:,200),'-',x,T(:,400),'-')
a = legend('t = 0 atau t = 1', 't = 250', 't = 200','t = 400');
```

```
set(a,'FontAngle','italic')
title 'Temperatur Metode Eksplisit Bahan Multilayer'
xlabel 'Sumbu-X'
ylabel 'Temperatur'

figure(2)
axis tight
mesh(x,time,T')
title 'Temperatur Metode Eksplisit Bahan Multilayer'
camzoom(1.2)
view(-35.5,35);
xlabel 'Sumbu-X'
ylabel 'Waktu'
zlabel 'Temperatur'

figure(3)
axis tight
C = contourf(x,time,T');
clabel(C)
title 'Temperatur Metode Eksplisit Bahan Multilayer'
xlabel 'Sumbu-X'
ylabel 'Waktu'
zlabel 'Temperatur'

figure(4)
plot(time,T(1,:)','-',time,T(10,:)','-',time,T(20,:)','-',time,T(25,:)','-',...
    time,T(30,:)','-',time,T(40,:)','-');
b = legend('x = 0','x = 10','x = 20','x = 25','x = 30','x = 40');
set(b,'FontAngle','italic')
title 'Temperatur Metode Eksplisit Bahan Multilayer'
xlabel 'Sumbu-X'
ylabel 'Temperatur'

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,2500))     % menampilkan data pada t = 2500
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Multilayer 1 Dimensi Numerik');
data = {x(1), T(1,1), T(1,50), T(1,100), T(1,500), T(1,1000), T(1,2000), T(1,2500);
        x(2), T(2,1), T(2,50), T(2,100), T(2,500), T(2,1000), T(2,2000), T(2,2500);
        x(3), T(3,1), T(3,50), T(3,100), T(3,500), T(3,1000), T(3,2000), T(3,2500);
        x(4), T(4,1), T(4,50), T(4,100), T(4,500), T(4,1000), T(4,2000), T(4,2500);
        x(5), T(5,1), T(5,50), T(5,100), T(5,500), T(5,1000), T(5,2000), T(5,2500);
        x(6), T(6,1), T(6,50), T(6,100), T(6,500), T(6,1000), T(6,2000), T(6,2500);
        x(7), T(7,1), T(7,50), T(7,100), T(7,500), T(7,1000), T(7,2000), T(7,2500);
        x(8), T(8,1), T(8,50), T(8,100), T(8,500), T(8,1000), T(8,2000), T(8,2500);
        x(9), T(9,1), T(9,50), T(9,100), T(9,500), T(9,1000), T(9,2000), T(9,2500);
        x(10), T(10,1), T(10,50), T(10,100), T(10,500), T(10,1000), T(10,2000), T(10,2500);
        x(11), T(11,1), T(11,50), T(11,100), T(11,500), T(11,1000), T(11,2000), T(11,2500);
        x(12), T(12,1), T(12,50), T(12,100), T(12,500), T(12,1000), T(12,2000), T(12,2500);
        x(13), T(13,1), T(13,50), T(13,100), T(13,500), T(13,1000), T(13,2000), T(13,2500);
        x(14), T(14,1), T(14,50), T(14,100), T(14,500), T(14,1000), T(14,2000), T(14,2500);
        x(15), T(15,1), T(15,50), T(15,100), T(15,500), T(15,1000), T(15,2000), T(15,2500);
        x(16), T(16,1), T(16,50), T(16,100), T(16,500), T(16,1000), T(16,2000), T(16,2500);
        x(17), T(17,1), T(17,50), T(17,100), T(17,500), T(17,1000), T(17,2000), T(17,2500);
        x(18), T(18,1), T(18,50), T(18,100), T(18,500), T(18,1000), T(18,2000), T(18,2500);
        x(19), T(19,1), T(19,50), T(19,100), T(19,500), T(19,1000), T(19,2000), T(19,2500);
        x(20), T(20,1), T(20,50), T(20,100), T(20,500), T(20,1000), T(20,2000), T(20,2500);
        x(21), T(21,1), T(21,50), T(21,100), T(21,500), T(21,1000), T(21,2000), T(21,2500);
        x(22), T(22,1), T(22,50), T(22,100), T(22,500), T(22,1000), T(22,2000), T(22,2500);
        x(23), T(23,1), T(23,50), T(23,100), T(23,500), T(23,1000), T(23,2000), T(23,2500);
        x(24), T(24,1), T(24,50), T(24,100), T(24,500), T(24,1000), T(24,2000), T(24,2500);
        x(25), T(25,1), T(25,50), T(25,100), T(25,500), T(25,1000), T(25,2000), T(25,2500);
        x(26), T(26,1), T(26,50), T(26,100), T(26,500), T(26,1000), T(26,2000), T(26,2500);
        x(27), T(27,1), T(27,50), T(27,100), T(27,500), T(27,1000), T(27,2000), T(27,2500);
        x(28), T(28,1), T(28,50), T(28,100), T(28,500), T(28,1000), T(28,2000), T(28,2500);
        x(29), T(29,1), T(29,50), T(29,100), T(29,500), T(29,1000), T(29,2000), T(29,2500);
        x(30), T(30,1), T(30,50), T(30,100), T(30,500), T(30,1000), T(30,2000), T(30,2500);
        x(31), T(31,1), T(31,50), T(31,100), T(31,500), T(31,1000), T(31,2000), T(31,2500);
        x(32), T(32,1), T(32,50), T(32,100), T(32,500), T(32,1000), T(32,2000), T(32,2500);
        x(33), T(33,1), T(33,50), T(33,100), T(33,500), T(33,1000), T(33,2000), T(33,2500);
        x(34), T(34,1), T(34,50), T(34,100), T(34,500), T(34,1000), T(34,2000), T(34,2500);
        x(35), T(35,1), T(35,50), T(35,100), T(35,500), T(35,1000), T(35,2000), T(35,2500);
        x(36), T(36,1), T(36,50), T(36,100), T(36,500), T(36,1000), T(36,2000), T(36,2500);
        x(37), T(37,1), T(37,50), T(37,100), T(37,500), T(37,1000), T(37,2000), T(37,2500);
        x(38), T(38,1), T(38,50), T(38,100), T(38,500), T(38,1000), T(38,2000), T(38,2500);
        x(39), T(39,1), T(39,50), T(39,100), T(39,500), T(39,1000), T(39,2000), T(39,2500);
        x(40), T(40,1), T(40,50), T(40,100), T(40,500), T(40,1000), T(40,2000), T(40,2500);
        x(41), T(41,1), T(41,50), T(41,100), T(41,500), T(41,1000), T(41,2000), T(41,2500);};

columnname = {'Sumbu-x','T(x,1)','T(x,50)','T(x,100)','T(x,500)',...
    'T(x,1000)','T(x,2000)','T(x,2500)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long','long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Distribusi suhu analitik 2 dimensi pada bahan Aluminium
% T(t,x,y) = exp(-2*(pi^2)*t))*sin(pi*(x))*sin(pi*(y))
% Kondisi awal T0 = sin(pi*(x))*sin(pi*(y))
% Bahan Aluminium difusivitas 0.000971348 ~ 0.000971
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
```

```
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% inisialisasi parameter masukan

l = 50;                 % panjang x
m = l;                  % panjang y
x = [0:l/50:l];         % lebar grid x
y = x;                  % lebar grid y
t = [0:1:4500];         % waktu iterasi 0 sampai dengan 4500
dif = 0.000971;         % difusivitas bahan Aluminium
%T0 = sin(pi*x/50).*sin(pi*y/50);   % temperatur awal

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menggunkan persamaan difusi 2 dimensi analitik

for n = 1:max(size(t))
    for j = 1:max(size(y))
        for i = 1:max(size(x))
            T(i,j,n) = exp(-2.*dif.*(pi.^2).*t(n)/l.^2)...
                .*sin(pi.*(x(i))/l).*sin(pi.*(y(j))/m);
        end
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik difusi 2 dimensi analitik

%figure(1)
%axis tight
%plot3(x,y,ci)

figure(2)
axis tight
a = mesh(x,y,T(:,:,max(size(t))));
title 'Difusi Suhu Bahan Aluminium 2 Dimensi Analitik'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Sumbu-z
view(-38.5,40)
set(a,'FaceColor','interp','EdgeColor','none','DiffuseStrength',1)
lighting phong
camlight

figure(3)
axis tight
format short
C = contourf(x,y,T(:,:,max(size(t))));
clabel(C)
title 'Difusi Suhu Bahan Aluminium 2 Dimensi Analitik'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Temperatur

figure(4)
axis tight
format short
C = contour3(x,y,T(:,:,max(size(t))),15);
clabel(C)
view(-38.5,40)
title 'Difusi Suhu Bahan Aluminium 2 Dimensi Analitik'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Temperatur

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,:,4500))      % menampilkan data pada t = 4500
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Aluminium 2 Dimensi
Analitik');
data = {'(1,1)', T(1,1,1), T(1,1,100), T(1,1,500), T(1,1,1000), T(1,1,2000), T(1,1,4500);
        '(2,2)', T(2,2,1), T(2,2,100), T(2,2,500), T(2,2,1000), T(2,2,2000), T(2,2,4500);
        '(3,3)', T(3,3,1), T(3,3,100), T(3,3,500), T(3,3,1000), T(3,3,2000), T(3,3,4500);
        '(4,4)', T(4,4,1), T(4,4,100), T(4,4,500), T(4,4,1000), T(4,4,2000), T(4,4,4500);
        '(5,5)', T(5,5,1), T(5,5,100), T(5,5,500), T(5,5,1000), T(5,5,2000), T(5,5,4500);
        '(6,6)', T(6,6,1), T(6,6,100), T(6,6,500), T(6,6,1000), T(6,6,2000), T(6,6,4500);
        '(7,7)', T(7,7,1), T(7,7,100), T(7,7,500), T(7,7,1000), T(7,7,2000), T(7,7,4500);
        '(8,8)', T(8,8,1), T(8,8,100), T(8,8,500), T(8,8,1000), T(8,8,2000), T(8,8,4500);
        '(9,9)', T(9,9,1), T(9,9,100), T(9,9,500), T(9,9,1000), T(9,9,2000), T(9,9,4500);
```

```
        '(10,10)', T(10,10,1), T(10,10,100), T(10,10,500), T(10,10,1000), T(10,10,2000),
T(10,10,4500);
        '(11,11)', T(11,11,1), T(11,11,100), T(11,11,500), T(11,11,1000), T(11,11,2000),
T(11,11,4500);
        '(12,12)', T(12,12,1), T(12,12,100), T(12,12,500), T(12,12,1000), T(12,12,2000),
T(12,12,4500);
        '(13,13)', T(13,13,1), T(13,13,100), T(13,13,500), T(13,13,1000), T(13,13,2000),
T(13,13,4500);
        '(14,14)', T(14,14,1), T(14,14,100), T(14,14,500), T(14,14,1000), T(14,14,2000),
T(14,14,4500);
        '(15,15)', T(15,15,1), T(15,15,100), T(15,15,500), T(15,15,1000), T(15,15,2000),
T(15,15,4500);
        '(16,16)', T(16,16,1), T(16,16,100), T(16,16,500), T(16,16,1000), T(16,16,2000),
T(16,16,4500);
        '(17,17)', T(17,17,1), T(17,17,100), T(17,17,500), T(17,17,1000), T(17,17,2000),
T(17,17,4500);
        '(18,18)', T(18,18,1), T(18,18,100), T(18,18,500), T(18,18,1000), T(18,18,2000),
T(18,18,4500);
        '(19,19)', T(19,19,1), T(19,19,100), T(19,19,500), T(19,19,1000), T(19,19,2000),
T(19,19,4500);
        '(20,20)', T(20,20,1), T(20,20,100), T(20,20,500), T(20,20,1000), T(20,20,2000),
T(20,20,4500);
        '(21,21)', T(21,21,1), T(21,21,100), T(21,21,500), T(21,21,1000), T(21,21,2000),
T(21,21,4500);
        '(22,22)', T(22,22,1), T(22,22,100), T(22,22,500), T(22,22,1000), T(22,22,2000),
T(22,22,4500);
        '(23,23)', T(23,23,1), T(23,23,100), T(23,23,500), T(23,23,1000), T(23,23,2000),
T(23,23,4500);
        '(24,24)', T(24,24,1), T(24,24,100), T(24,24,500), T(24,24,1000), T(24,24,2000),
T(24,24,4500);
        '(25,25)', T(25,25,1), T(25,25,100), T(25,25,500), T(25,25,1000), T(25,25,2000),
T(25,25,4500);
        '(26,26)', T(26,26,1), T(26,26,100), T(26,26,500), T(26,26,1000), T(26,26,2000),
T(26,26,4500);
        '(27,27)', T(27,27,1), T(27,27,100), T(27,27,500), T(27,27,1000), T(27,27,2000),
T(27,27,4500);
        '(28,28)', T(28,28,1), T(28,28,100), T(28,28,500), T(28,28,1000), T(28,28,2000),
T(28,28,4500);
        '(29,29)', T(29,29,1), T(29,29,100), T(29,29,500), T(29,29,1000), T(29,29,2000),
T(29,29,4500);
        '(30,30)', T(30,30,1), T(30,30,100), T(30,30,500), T(30,30,1000), T(30,30,2000),
T(30,30,4500);
        '(31,31)', T(31,31,1), T(31,31,100), T(31,31,500), T(31,31,1000), T(31,31,2000),
T(31,31,4500);
        '(32,32)', T(32,32,1), T(32,32,100), T(32,32,500), T(32,32,1000), T(32,32,2000),
T(33,33,4500);
        '(33,33)', T(33,33,1), T(33,33,100), T(33,33,500), T(33,33,1000), T(33,33,2000),
T(33,33,4500);
        '(34,34)', T(34,34,1), T(34,34,100), T(34,34,500), T(34,34,1000), T(34,34,2000),
T(34,34,4500);
        '(35,35)', T(35,35,1), T(35,35,100), T(35,35,500), T(35,35,1000), T(35,35,2000),
T(35,35,4500);
        '(36,36)', T(36,36,1), T(36,36,100), T(36,36,500), T(36,36,1000), T(36,36,2000),
T(36,36,4500);
        '(37,37)', T(37,37,1), T(37,37,100), T(37,37,500), T(37,37,1000), T(37,37,2000),
T(37,37,4500);
        '(38,38)', T(38,38,1), T(38,38,100), T(38,38,500), T(38,38,1000), T(38,38,2000),
T(38,38,4500);
        '(39,39)', T(39,39,1), T(39,39,100), T(39,39,500), T(39,39,1000), T(39,39,2000),
T(39,39,4500);
        '(40,40)', T(40,40,1), T(40,40,100), T(40,40,500), T(40,40,1000), T(40,40,2000),
T(40,40,4500);
        '(41,41)', T(41,41,1), T(41,41,100), T(41,41,500), T(41,41,1000), T(41,41,2000),
T(41,41,4500);
        '(42,42)', T(42,42,1), T(42,42,100), T(42,42,500), T(42,42,1000), T(42,42,2000),
T(42,42,4500);
        '(43,43)', T(43,43,1), T(43,43,100), T(43,43,500), T(43,43,1000), T(42,42,2000),
T(43,43,4500);
        '(44,44)', T(44,44,1), T(44,44,100), T(44,44,500), T(44,44,1000), T(44,44,2000),
T(44,44,4500);
        '(45,45)', T(45,45,1), T(45,45,100), T(45,45,500), T(45,45,1000), T(45,45,2000),
T(45,45,4500);
        '(46,46)', T(46,46,1), T(46,46,100), T(46,46,500), T(46,46,1000), T(46,46,2000),
T(46,46,4500);
        '(47,47)', T(47,47,1), T(47,47,100), T(47,47,500), T(47,47,1000), T(47,47,2000),
T(47,47,4500);
        '(48,48)', T(48,48,1), T(48,48,100), T(48,48,500), T(48,48,1000), T(48,48,2000),
T(48,48,4500);
        '(49,49)', T(49,49,1), T(49,49,100), T(49,49,500), T(49,49,1000), T(49,49,2000),
T(49,49,4500);
        '(50,50)', T(50,50,1), T(50,50,100), T(50,50,500), T(50,50,1000), T(50,50,2000),
T(50,50,4500);
        '(51,51)', T(51,51,1), T(51,51,100), T(51,51,500), T(51,51,1000), T(51,51,2000),
T(51,51,4500);};
```

```matlab
columnname = {'Sumbu-xy','T(x,y,1)','T(x,y,100)','T(x,y,500)','T(x,y,1000)',...
    'T(x,y,2000)','T(x,y,4500)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);



%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Distribusi suhu analitik 2 dimensi pada bahan Perak
% T(t,x,y) = exp(-2*(pi^2)*t))*sin(pi*(x))*sin(pi*(y))
% Kondisi awal T0 = sin(pi*(x))*sin(pi*(y))
% Bahan Perak difusivitas 0.173860182 ~ 0.00174
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% inisialisasi parameter masukan

l = 50;                 % panjang x
m = l;                  % panjang y
x = [0:l/50:l];         % lebar grid x
y = x;                  % lebar grid y
t = [0:1:4500];         % waktu iterasi 0 sampai dengan 4500
dif = 0.00174;          % difusivitas bahan perak
%T0 = sin(pi*x/50).*sin(pi*y/50);   % temperatur awal

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menggunkan persamaan difusi 2 dimensi analitik

for n = 1:max(size(t))
    for j = 1:max(size(y))
        for i = 1:max(size(x))
            T(i,j,n) = exp(-2.*dif.*(pi.^2).*t(n)/l.^2)...
                .*sin(pi.*(x(i))/l).*sin(pi.*(y(j))/m);
        end
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik difusi 2 dimensi analitik

%figure(1)
%axis tight
%plot3(x,y,T0)

figure(2)
axis tight
a = mesh(x,y,T(:,:,max(size(t))));
title 'Difusi Suhu Bahan Perak 2 Dimensi Analitik'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Temperatur
view(-38.5,40);
set(a,'FaceColor','interp','EdgeColor','none','DiffuseStrength',1)
lighting phong
camlight

figure(3)
axis tight
format short
C = contourf(x,y,T(:,:,max(size(t))));
clabel(C)
title 'Difusi Suhu Bahan Perak 2 Dimensi Analitk'
xlabel Sumbu-x
ylabel Sumbu-y

figure(4)
axis tight
format short
C = contour3(x,y,T(:,:,max(size(t))),15);
clabel(C)
view(-38.5,40)
title 'Difusi Suhu Bahan Perak 2 Dimensi Analitik'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Temperatur
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,:,4500))     % menampilkan data pada t = 4500
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Perak 2 Dimensi
Analitik');
data = {'(1,1)', T(1,1,1), T(1,1,100), T(1,1,500), T(1,1,1000), T(1,1,2000), T(1,1,4500);
        '(2,2)', T(2,2,1), T(2,2,100), T(2,2,500), T(2,2,1000), T(2,2,2000), T(2,2,4500);
        '(3,3)', T(3,3,1), T(3,3,100), T(3,3,500), T(3,3,1000), T(3,3,2000), T(3,3,4500);
        '(4,4)', T(4,4,1), T(4,4,100), T(4,4,500), T(4,4,1000), T(4,4,2000), T(4,4,4500);
        '(5,5)', T(5,5,1), T(5,5,100), T(5,5,500), T(5,5,1000), T(5,5,2000), T(5,5,4500);
        '(6,6)', T(6,6,1), T(6,6,100), T(6,6,500), T(6,6,1000), T(6,6,2000), T(6,6,4500);
        '(7,7)', T(7,7,1), T(7,7,100), T(7,7,500), T(7,7,1000), T(7,7,2000), T(7,7,4500);
        '(8,8)', T(8,8,1), T(8,8,100), T(8,8,500), T(8,8,1000), T(8,8,2000), T(8,8,4500);
        '(9,9)', T(9,9,1), T(9,9,100), T(9,9,500), T(9,9,1000), T(9,9,2000), T(9,9,4500);
        '(10,10)', T(10,10,1), T(10,10,100), T(10,10,500), T(10,10,1000), T(10,10,2000),
T(10,10,4500);
        '(11,11)', T(11,11,1), T(11,11,100), T(11,11,500), T(11,11,1000), T(11,11,2000),
T(11,11,4500);
        '(12,12)', T(12,12,1), T(12,12,100), T(12,12,500), T(12,12,1000), T(12,12,2000),
T(12,12,4500);
        '(13,13)', T(13,13,1), T(13,13,100), T(13,13,500), T(13,13,1000), T(13,13,2000),
T(13,13,4500);
        '(14,14)', T(14,14,1), T(14,14,100), T(14,14,500), T(14,14,1000), T(14,14,2000),
T(14,14,4500);
        '(15,15)', T(15,15,1), T(15,15,100), T(15,15,500), T(15,15,1000), T(15,15,2000),
T(15,15,4500);
        '(16,16)', T(16,16,1), T(16,16,100), T(16,16,500), T(16,16,1000), T(16,16,2000),
T(16,16,4500);
        '(17,17)', T(17,17,1), T(17,17,100), T(17,17,500), T(17,17,1000), T(17,17,2000),
T(17,17,4500);
        '(18,18)', T(18,18,1), T(18,18,100), T(18,18,500), T(18,18,1000), T(18,18,2000),
T(18,18,4500);
        '(19,19)', T(19,19,1), T(19,19,100), T(19,19,500), T(19,19,1000), T(19,19,2000),
T(19,19,4500);
        '(20,20)', T(20,20,1), T(20,20,100), T(20,20,500), T(20,20,1000), T(20,20,2000),
T(20,20,4500);
        '(21,21)', T(21,21,1), T(21,21,100), T(21,21,500), T(21,21,1000), T(21,21,2000),
T(21,21,4500);
        '(22,22)', T(22,22,1), T(22,22,100), T(22,22,500), T(22,22,1000), T(22,22,2000),
T(22,22,4500);
        '(23,23)', T(23,23,1), T(23,23,100), T(23,23,500), T(23,23,1000), T(23,23,2000),
T(23,23,4500);
        '(24,24)', T(24,24,1), T(24,24,100), T(24,24,500), T(24,24,1000), T(24,24,2000),
T(24,24,4500);
        '(25,25)', T(25,25,1), T(25,25,100), T(25,25,500), T(25,25,1000), T(25,25,2000),
T(25,25,4500);
        '(26,26)', T(26,26,1), T(26,26,100), T(26,26,500), T(26,26,1000), T(26,26,2000),
T(26,26,4500);
        '(27,27)', T(27,27,1), T(27,27,100), T(27,27,500), T(27,27,1000), T(27,27,2000),
T(27,27,4500);
        '(28,28)', T(28,28,1), T(28,28,100), T(28,28,500), T(28,28,1000), T(28,28,2000),
T(28,28,4500);
        '(29,29)', T(29,29,1), T(29,29,100), T(29,29,500), T(29,29,1000), T(29,29,2000),
T(29,29,4500);
        '(30,30)', T(30,30,1), T(30,30,100), T(30,30,500), T(30,30,1000), T(30,30,2000),
T(30,30,4500);
        '(31,31)', T(31,31,1), T(31,31,100), T(31,31,500), T(31,31,1000), T(31,31,2000),
T(31,31,4500);
        '(32,32)', T(32,32,1), T(32,32,100), T(32,32,500), T(32,32,1000), T(32,32,2000),
T(33,33,4500);
        '(33,33)', T(33,33,1), T(33,33,100), T(33,33,500), T(33,33,1000), T(33,33,2000),
T(33,33,4500);
        '(34,34)', T(34,34,1), T(34,34,100), T(34,34,500), T(34,34,1000), T(34,34,2000),
T(34,34,4500);
        '(35,35)', T(35,35,1), T(35,35,100), T(35,35,500), T(35,35,1000), T(35,35,2000),
T(35,35,4500);
        '(36,36)', T(36,36,1), T(36,36,100), T(36,36,500), T(36,36,1000), T(36,36,2000),
T(36,36,4500);
        '(37,37)', T(37,37,1), T(37,37,100), T(37,37,500), T(37,37,1000), T(37,37,2000),
T(37,37,4500);
        '(38,38)', T(38,38,1), T(38,38,100), T(38,38,500), T(38,38,1000), T(38,38,2000),
T(38,38,4500);
        '(39,39)', T(39,39,1), T(39,39,100), T(39,39,500), T(39,39,1000), T(39,39,2000),
T(39,39,4500);
        '(40,40)', T(40,40,1), T(40,40,100), T(40,40,500), T(40,40,1000), T(40,40,2000),
T(40,40,4500);
        '(41,41)', T(41,41,1), T(41,41,100), T(41,41,500), T(41,41,1000), T(41,41,2000),
T(41,41,4500);
        '(42,42)', T(42,42,1), T(42,42,100), T(42,42,500), T(42,42,1000), T(42,42,2000),
T(42,42,4500);
        '(43,43)', T(43,43,1), T(43,43,100), T(43,43,500), T(43,43,1000), T(42,42,2000),
T(43,43,4500);
```

```
        '(44,44)', T(44,44,1), T(44,44,100), T(44,44,500), T(44,44,1000), T(44,44,2000),
T(44,44,4500);
        '(45,45)', T(45,45,1), T(45,45,100), T(45,45,500), T(45,45,1000), T(45,45,2000),
T(45,45,4500);
        '(46,46)', T(46,46,1), T(46,46,100), T(46,46,500), T(46,46,1000), T(46,46,2000),
T(46,46,4500);
        '(47,47)', T(47,47,1), T(47,47,100), T(47,47,500), T(47,47,1000), T(47,47,2000),
T(47,47,4500);
        '(48,48)', T(48,48,1), T(48,48,100), T(48,48,500), T(48,48,1000), T(48,48,2000),
T(48,48,4500);
        '(49,49)', T(49,49,1), T(49,49,100), T(49,49,500), T(49,49,1000), T(49,49,2000),
T(49,49,4500);
        '(50,50)', T(50,50,1), T(50,50,100), T(50,50,500), T(50,50,1000), T(50,50,2000),
T(50,50,4500);
        '(51,51)', T(51,51,1), T(51,51,100), T(51,51,500), T(51,51,1000), T(51,51,2000),
T(51,51,4500);};

columnname = {'Sumbu-xy','T(x,y,1)','T(x,y,100)','T(x,y,500)','T(x,y,1000)',...
    'T(x,y,2000)','T(x,y,4500)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Distribusi suhu numerik 2 dimensi pada bahan Aluminium
% Metode ini menggunakan metode beda hingga
% Skema yang digunakan adalah skema Eksplisit (FTCS)
% Bahan Aluminium difusivitas 0.000971348 ~ 0.000971
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% inisialisasi parameter masukan

L = 1.;                              % panjang x
M = L;                               % panjang y
Takhir = 250;                        % waktu akhir
Tmax_step = 4500;                    % waktu step
dt = Takhir/Tmax_step;               % delta t
nmax_step = 50;                      % jarak step
dx = L/nmax_step;                    % delta x
dy = dx;                             % delta y

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% sifat fisis bahan

% kond = 237;                        % konduktivitas bahan
% Cp = 903;                          % panas spesifik bahan
% rho = 2702.;                       % massa jenis bahan
dif = 0.000971;                      % difusivitas = cond/(spheat*rho);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% parameter masukan nilai r

r = dif*dt/(dx.^2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% kondisi awal

for i = 1:nmax_step+1
    x(i) = (i-1)*dx;
    y(i) = (i-1)*dy;
    T(1:nmax_step+1,1:nmax_step+1,1) = sin(pi*(x(i))).*sin(pi*(y(i)));
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% kondisi batas

for n = 1:Tmax_step+1
    for j = 1:nmax_step+1
       for i = 1:nmax_step+1
           T(n) = (n-1)*dt;
           T(1,1:nmax_step+1,n) = 0;
           T(1:nmax_step+1,1,n) = 0;
           T(nmax_step+1,1:nmax_step+1,n) = 0;
           T(1:nmax_step+1,nmax_step+1,n) = 0;
       end
    end
```

```
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% metode FTCS

for n = 1:Tmax_step
    for j = 2:nmax_step
        for i = 2:nmax_step
            T(i,j,n+1) = (1-4*r)*T(i,j,n) + r*(T(i-1,j,n)+T(i+1,j,n)+...
                T(i,j-1,n)+T(i,j+1,n));
                %((2-4*r)*T(i,j,n)+r*(T(i+1,j,n)+T(i-1,j,n)+T(i,j+1,n)...
                % +T(i,j-1,n))+r*(T(i+1,j,n+1)+T(i-1,j,n+1)+T(i,j+1,n+1)+...
                % T(i,j-1,n+1)))/(2+4*r);
        end
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik difusi 2 dimensi

figure(1)
axis tight
a = mesh(x,y,T(:,:,Tmax_step)');
title 'Difusi Suhu Bahan Aluminium 2 Dimensi Metode FTCS'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Temperatur
view(-38.5,40);
set(a,'FaceColor','interp','EdgeColor','none','DiffuseStrength',1)
lighting phong
camlight

figure(2)
axis tight
C = contourf(x,y,T(:,:,Tmax_step)');
%,'-',x,y,T(:,:,20),'-',x,y,T(:,:,40)','-',x,y,T(:,:,80)','-',x,y,T(:,:,100)','-')
clabel(C)
title 'Difusi Suhu Bahan Aluminium 2 Dimensi Metode FTCS'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Temperatur

figure(3)
axis tight
format short
C = contour3(x,y,T(:,:,Tmax_step),15);
clabel(C)
view(-38.5,40)
title 'Difusi Suhu Bahan Aluminium 2 Dimensi Metode FTCS'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Temperatur

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,:,4500))      % menampilkan data pada t = 4500
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Aluminium 2 Dimensi
Metode FTCS');
data = {'(1,1)', T(1,1,1), T(1,1,100), T(1,1,500), T(1,1,1000), T(1,1,2000), T(1,1,4500);
        '(2,2)', T(2,2,1), T(2,2,100), T(2,2,500), T(2,2,1000), T(2,2,2000), T(2,2,4500);
        '(3,3)', T(3,3,1), T(3,3,100), T(3,3,500), T(3,3,1000), T(3,3,2000), T(3,3,4500);
        '(4,4)', T(4,4,1), T(4,4,100), T(4,4,500), T(4,4,1000), T(4,4,2000), T(4,4,4500);
        '(5,5)', T(5,5,1), T(5,5,100), T(5,5,500), T(5,5,1000), T(5,5,2000), T(5,5,4500);
        '(6,6)', T(6,6,1), T(6,6,100), T(6,6,500), T(6,6,1000), T(6,6,2000), T(6,6,4500);
        '(7,7)', T(7,7,1), T(7,7,100), T(7,7,500), T(7,7,1000), T(7,7,2000), T(7,7,4500);
        '(8,8)', T(8,8,1), T(8,8,100), T(8,8,500), T(8,8,1000), T(8,8,2000), T(8,8,4500);
        '(9,9)', T(9,9,1), T(9,9,100), T(9,9,500), T(9,9,1000), T(9,9,2000), T(9,9,4500);
        '(10,10)', T(10,10,1), T(10,10,100), T(10,10,500), T(10,10,1000), T(10,10,2000),
T(10,10,4500);
        '(11,11)', T(11,11,1), T(11,11,100), T(11,11,500), T(11,11,1000), T(11,11,2000),
T(11,11,4500);
        '(12,12)', T(12,12,1), T(12,12,100), T(12,12,500), T(12,12,1000), T(12,12,2000),
T(12,12,4500);
        '(13,13)', T(13,13,1), T(13,13,100), T(13,13,500), T(13,13,1000), T(13,13,2000),
T(13,13,4500);
        '(14,14)', T(14,14,1), T(14,14,100), T(14,14,500), T(14,14,1000), T(14,14,2000),
T(14,14,4500);
        '(15,15)', T(15,15,1), T(15,15,100), T(15,15,500), T(15,15,1000), T(15,15,2000),
T(15,15,4500);
        '(16,16)', T(16,16,1), T(16,16,100), T(16,16,500), T(16,16,1000), T(16,16,2000),
T(16,16,4500);
```

```
        '(17,17)', T(17,17,1), T(17,17,100), T(17,17,500), T(17,17,1000), T(17,17,2000),
T(17,17,4500);
        '(18,18)', T(18,18,1), T(18,18,100), T(18,18,500), T(18,18,1000), T(18,18,2000),
T(18,18,4500);
        '(19,19)', T(19,19,1), T(19,19,100), T(19,19,500), T(19,19,1000), T(19,19,2000),
T(19,19,4500);
        '(20,20)', T(20,20,1), T(20,20,100), T(20,20,500), T(20,20,1000), T(20,20,2000),
T(20,20,4500);
        '(21,21)', T(21,21,1), T(21,21,100), T(21,21,500), T(21,21,1000), T(21,21,2000),
T(21,21,4500);
        '(22,22)', T(22,22,1), T(22,22,100), T(22,22,500), T(22,22,1000), T(22,22,2000),
T(22,22,4500);
        '(23,23)', T(23,23,1), T(23,23,100), T(23,23,500), T(23,23,1000), T(23,23,2000),
T(23,23,4500);
        '(24,24)', T(24,24,1), T(24,24,100), T(24,24,500), T(24,24,1000), T(24,24,2000),
T(24,24,4500);
        '(25,25)', T(25,25,1), T(25,25,100), T(25,25,500), T(25,25,1000), T(25,25,2000),
T(25,25,4500);
        '(26,26)', T(26,26,1), T(26,26,100), T(26,26,500), T(26,26,1000), T(26,26,2000),
T(26,26,4500);
        '(27,27)', T(27,27,1), T(27,27,100), T(27,27,500), T(27,27,1000), T(27,27,2000),
T(27,27,4500);
        '(28,28)', T(28,28,1), T(28,28,100), T(28,28,500), T(28,28,1000), T(28,28,2000),
T(28,28,4500);
        '(29,29)', T(29,29,1), T(29,29,100), T(29,29,500), T(29,29,1000), T(29,29,2000),
T(29,29,4500);
        '(30,30)', T(30,30,1), T(30,30,100), T(30,30,500), T(30,30,1000), T(30,30,2000),
T(30,30,4500);
        '(31,31)', T(31,31,1), T(31,31,100), T(31,31,500), T(31,31,1000), T(31,31,2000),
T(31,31,4500);
        '(32,32)', T(32,32,1), T(32,32,100), T(32,32,500), T(32,32,1000), T(32,32,2000),
T(33,33,4500);
        '(33,33)', T(33,33,1), T(33,33,100), T(33,33,500), T(33,33,1000), T(33,33,2000),
T(33,33,4500);
        '(34,34)', T(34,34,1), T(34,34,100), T(34,34,500), T(34,34,1000), T(34,34,2000),
T(34,34,4500);
        '(35,35)', T(35,35,1), T(35,35,100), T(35,35,500), T(35,35,1000), T(35,35,2000),
T(35,35,4500);
        '(36,36)', T(36,36,1), T(36,36,100), T(36,36,500), T(36,36,1000), T(36,36,2000),
T(36,36,4500);
        '(37,37)', T(37,37,1), T(37,37,100), T(37,37,500), T(37,37,1000), T(37,37,2000),
T(37,37,4500);
        '(38,38)', T(38,38,1), T(38,38,100), T(38,38,500), T(38,38,1000), T(38,38,2000),
T(38,38,4500);
        '(39,39)', T(39,39,1), T(39,39,100), T(39,39,500), T(39,39,1000), T(39,39,2000),
T(39,39,4500);
        '(40,40)', T(40,40,1), T(40,40,100), T(40,40,500), T(40,40,1000), T(40,40,2000),
T(40,40,4500);
        '(41,41)', T(41,41,1), T(41,41,100), T(41,41,500), T(41,41,1000), T(41,41,2000),
T(41,41,4500);
        '(42,42)', T(42,42,1), T(42,42,100), T(42,42,500), T(42,42,1000), T(42,42,2000),
T(42,42,4500);
        '(43,43)', T(43,43,1), T(43,43,100), T(43,43,500), T(43,43,1000), T(42,42,2000),
T(43,43,4500);
        '(44,44)', T(44,44,1), T(44,44,100), T(44,44,500), T(44,44,1000), T(44,44,2000),
T(44,44,4500);
        '(45,45)', T(45,45,1), T(45,45,100), T(45,45,500), T(45,45,1000), T(45,45,2000),
T(45,45,4500);
        '(46,46)', T(46,46,1), T(46,46,100), T(46,46,500), T(46,46,1000), T(46,46,2000),
T(46,46,4500);
        '(47,47)', T(47,47,1), T(47,47,100), T(47,47,500), T(47,47,1000), T(47,47,2000),
T(47,47,4500);
        '(48,48)', T(48,48,1), T(48,48,100), T(48,48,500), T(48,48,1000), T(48,48,2000),
T(48,48,4500);
        '(49,49)', T(49,49,1), T(49,49,100), T(49,49,500), T(49,49,1000), T(49,49,2000),
T(49,49,4500);
        '(50,50)', T(50,50,1), T(50,50,100), T(50,50,500), T(50,50,1000), T(50,50,2000),
T(50,50,4500);
        '(51,51)', T(51,51,1), T(51,51,100), T(51,51,500), T(51,51,1000), T(51,51,2000),
T(51,51,4500);};

columnname = {'Sumbu-xy','T(x,y,1)','T(x,y,100)','T(x,y,500)','T(x,y,1000)',...
    'T(x,y,2000)','T(x,y,4500)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Distribusi suhu numerik 2 dimensi pada bahan Perak
% Metode ini menggunakan metode beda hingga
% Skema yang digunakan adalah skema Eksplisit (FTCS)
% Bahan Perak difusivitas 0.00173860182 ~ 0.00174
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% inisialisasi parameter masukan

L = 1.;                          % panjang x
M = L;                           % panjang y
Takhir = 118.75;                 % waktu akhir 119
Tmax_step = 4500;                % waktu step
dt = Takhir/Tmax_step;           % delta t
nmax_step = 50;                  % jarak step
dx = L/nmax_step;                % delta x
dy = dx;                         % delta y

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% sifat fisis bahan

% kond = 429.;                   % konduktivitas bahan
% Cp = 235.;                     % panas spesifik
% rho = 10500.;                  % massa jenis bahan
dif = 0.00174;                   % difusivitas = cond/(spheat*rho);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% parameter masukan nilai r

r = dif*dt/(dx.^2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% kondisi awal

for i = 1:nmax_step+1
    x(i) = (i-1)*dx;
    y(i) = (i-1)*dy;
    T(1,1,1) = sin(pi*(x(i))).*sin(pi*(y(i)));
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% kondisi batas

for n = 1:Tmax_step+1
    for j = 1:nmax_step+1
       for i = 1:nmax_step+1
           T(n) = (n-1)*dt;
           T(1,1:nmax_step+1,n) = 0;
           T(1:nmax_step+1,1,n) = 0;
           T(nmax_step+1,1:nmax_step+1,n) = 0;
           T(1:nmax_step+1,nmax_step+1,n) = 0;
       end
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% metode FTCS

for n = 1:Tmax_step
    for j = 2:nmax_step
        for i = 2:nmax_step
            T(i,j,n+1) = (1-4*r)*T(i,j,n) + r*(T(i-1,j,n)+T(i+1,j,n)+...
                T(i,j-1,n)+T(i,j+1,n));
                %((2-4*r)*T(i,j,n)+r*(T(i+1,j,n)+T(i-1,j,n)+T(i,j+1,n)...
                % +T(i,j-1,n))+r*(T(i+1,j,n+1)+T(i-1,j,n+1)+T(i,j+1,n+1)+...
                % T(i,j-1,n+1)))/(2+4*r);   % skema Crank-Nicolson
        end
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik difusi 2 dimensi

figure(1)
axis tight
dif = mesh(x,y,T(:,:,Tmax_step)');
title 'Difusi Suhu Bahan Perak 2 Dimensi Metode FTCS'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Temperatur
view(-38.5,40);
set(dif,'FaceColor','interp','EdgeColor','none','DiffuseStrength',1)
lighting phong
```

```
camlight

figure(2)
axis tight
C = contourf(x,y,T(:,:,Tmax_step)');
clabel(C)
title 'Difusi Suhu Bahan Perak 2 Dimensi Metode FTCS'
xlabel Sumbu-x
ylabel Sumbu-y

figure(3)
axis tight
format short
C = contour3(x,y,T(:,:,Tmax_step),15);
clabel(C)
view(-38.5,40)
title 'Difusi Suhu Bahan Perak 2 Dimensi Metode FTCS'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Temperatur

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,:,4500))      % menampilkan data pada t = 4500
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Perak 2 Dimensi Metode
FTCS');
data = {'(1,1)', T(1,1,1), T(1,1,100), T(1,1,500), T(1,1,1000), T(1,1,2000), T(1,1,4500);
        '(2,2)', T(2,2,1), T(2,2,100), T(2,2,500), T(2,2,1000), T(2,2,2000), T(2,2,4500);
        '(3,3)', T(3,3,1), T(3,3,100), T(3,3,500), T(3,3,1000), T(3,3,2000), T(3,3,4500);
        '(4,4)', T(4,4,1), T(4,4,100), T(4,4,500), T(4,4,1000), T(4,4,2000), T(4,4,4500);
        '(5,5)', T(5,5,1), T(5,5,100), T(5,5,500), T(5,5,1000), T(5,5,2000), T(5,5,4500);
        '(6,6)', T(6,6,1), T(6,6,100), T(6,6,500), T(6,6,1000), T(6,6,2000), T(6,6,4500);
        '(7,7)', T(7,7,1), T(7,7,100), T(7,7,500), T(7,7,1000), T(7,7,2000), T(7,7,4500);
        '(8,8)', T(8,8,1), T(8,8,100), T(8,8,500), T(8,8,1000), T(8,8,2000), T(8,8,4500);
        '(9,9)', T(9,9,1), T(9,9,100), T(9,9,500), T(9,9,1000), T(9,9,2000), T(9,9,4500);
        '(10,10)', T(10,10,1), T(10,10,100), T(10,10,500), T(10,10,1000), T(10,10,2000),
T(10,10,4500);
        '(11,11)', T(11,11,1), T(11,11,100), T(11,11,500), T(11,11,1000), T(11,11,2000),
T(11,11,4500);
        '(12,12)', T(12,12,1), T(12,12,100), T(12,12,500), T(12,12,1000), T(12,12,2000),
T(12,12,4500);
        '(13,13)', T(13,13,1), T(13,13,100), T(13,13,500), T(13,13,1000), T(13,13,2000),
T(13,13,4500);
        '(14,14)', T(14,14,1), T(14,14,100), T(14,14,500), T(14,14,1000), T(14,14,2000),
T(14,14,4500);
        '(15,15)', T(15,15,1), T(15,15,100), T(15,15,500), T(15,15,1000), T(15,15,2000),
T(15,15,4500);
        '(16,16)', T(16,16,1), T(16,16,100), T(16,16,500), T(16,16,1000), T(16,16,2000),
T(16,16,4500);
        '(17,17)', T(17,17,1), T(17,17,100), T(17,17,500), T(17,17,1000), T(17,17,2000),
T(17,17,4500);
        '(18,18)', T(18,18,1), T(18,18,100), T(18,18,500), T(18,18,1000), T(18,18,2000),
T(18,18,4500);
        '(19,19)', T(19,19,1), T(19,19,100), T(19,19,500), T(19,19,1000), T(19,19,2000),
T(19,19,4500);
        '(20,20)', T(20,20,1), T(20,20,100), T(20,20,500), T(20,20,1000), T(20,20,2000),
T(20,20,4500);
        '(21,21)', T(21,21,1), T(21,21,100), T(21,21,500), T(21,21,1000), T(21,21,2000),
T(21,21,4500);
        '(22,22)', T(22,22,1), T(22,22,100), T(22,22,500), T(22,22,1000), T(22,22,2000),
T(22,22,4500);
        '(23,23)', T(23,23,1), T(23,23,100), T(23,23,500), T(23,23,1000), T(23,23,2000),
T(23,23,4500);
        '(24,24)', T(24,24,1), T(24,24,100), T(24,24,500), T(24,24,1000), T(24,24,2000),
T(24,24,4500);
        '(25,25)', T(25,25,1), T(25,25,100), T(25,25,500), T(25,25,1000), T(25,25,2000),
T(25,25,4500);
        '(26,26)', T(26,26,1), T(26,26,100), T(26,26,500), T(26,26,1000), T(26,26,2000),
T(26,26,4500);
        '(27,27)', T(27,27,1), T(27,27,100), T(27,27,500), T(27,27,1000), T(27,27,2000),
T(27,27,4500);
        '(28,28)', T(28,28,1), T(28,28,100), T(28,28,500), T(28,28,1000), T(28,28,2000),
T(28,28,4500);
        '(29,29)', T(29,29,1), T(29,29,100), T(29,29,500), T(29,29,1000), T(29,29,2000),
T(29,29,4500);
        '(30,30)', T(30,30,1), T(30,30,100), T(30,30,500), T(30,30,1000), T(30,30,2000),
T(30,30,4500);
        '(31,31)', T(31,31,1), T(31,31,100), T(31,31,500), T(31,31,1000), T(31,31,2000),
T(31,31,4500);
        '(32,32)', T(32,32,1), T(32,32,100), T(32,32,500), T(32,32,1000), T(32,32,2000),
T(33,33,4500);
```

```
        '(33,33)', T(33,33,1), T(33,33,100), T(33,33,500), T(33,33,1000), T(33,33,2000),
T(33,33,4500);
        '(34,34)', T(34,34,1), T(34,34,100), T(34,34,500), T(34,34,1000), T(34,34,2000),
T(34,34,4500);
        '(35,35)', T(35,35,1), T(35,35,100), T(35,35,500), T(35,35,1000), T(35,35,2000),
T(35,35,4500);
        '(36,36)', T(36,36,1), T(36,36,100), T(36,36,500), T(36,36,1000), T(36,36,2000),
T(36,36,4500);
        '(37,37)', T(37,37,1), T(37,37,100), T(37,37,500), T(37,37,1000), T(37,37,2000),
T(37,37,4500);
        '(38,38)', T(38,38,1), T(38,38,100), T(38,38,500), T(38,38,1000), T(38,38,2000),
T(38,38,4500);
        '(39,39)', T(39,39,1), T(39,39,100), T(39,39,500), T(39,39,1000), T(39,39,2000),
T(39,39,4500);
        '(40,40)', T(40,40,1), T(40,40,100), T(40,40,500), T(40,40,1000), T(40,40,2000),
T(40,40,4500);
        '(41,41)', T(41,41,1), T(41,41,100), T(41,41,500), T(41,41,1000), T(41,41,2000),
T(41,41,4500);
        '(42,42)', T(42,42,1), T(42,42,100), T(42,42,500), T(42,42,1000), T(42,42,2000),
T(42,42,4500);
        '(43,43)', T(43,43,1), T(43,43,100), T(43,43,500), T(43,43,1000), T(42,42,2000),
T(43,43,4500);
        '(44,44)', T(44,44,1), T(44,44,100), T(44,44,500), T(44,44,1000), T(44,44,2000),
T(44,44,4500);
        '(45,45)', T(45,45,1), T(45,45,100), T(45,45,500), T(45,45,1000), T(45,45,2000),
T(45,45,4500);
        '(46,46)', T(46,46,1), T(46,46,100), T(46,46,500), T(46,46,1000), T(46,46,2000),
T(46,46,4500);
        '(47,47)', T(47,47,1), T(47,47,100), T(47,47,500), T(47,47,1000), T(47,47,2000),
T(47,47,4500);
        '(48,48)', T(48,48,1), T(48,48,100), T(48,48,500), T(48,48,1000), T(48,48,2000),
T(48,48,4500);
        '(49,49)', T(49,49,1), T(49,49,100), T(49,49,500), T(49,49,1000), T(49,49,2000),
T(49,49,4500);
        '(50,50)', T(50,50,1), T(50,50,100), T(50,50,500), T(50,50,1000), T(50,50,2000),
T(50,50,4500);
        '(51,51)', T(51,51,1), T(51,51,100), T(51,51,500), T(51,51,1000), T(51,51,2000),
T(51,51,4500);};

columnname = {'Sumbu-xy','T(x,y,1)','T(x,y,100)','T(x,y,500)','T(x,y,1000)',...
    'T(x,y,2000)','T(x,y,4500)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Difusi numerik 2 dimensi bahan sembarang
% Menggunakan iterasi Succesive Over Relaxation (SOR)
% Kondisi awal T0 = 1
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Inisialisasi parameter masukan

eps = .01;
omega = 1.6;

ip = 40;                % batas pada sumbu-x
jp = 20;                % batas pada sumbu-y
W = 1.;                 % panjang sumbu-x
L = 1.;                 % panjang sumbu-y
nx = 50;
ny = 50;
dx = L/nx;
rdx2 = 1./(dx*dx);
dy = W/ny;
rdy2 = 1./(dy*dy);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Kondisi awal
% temperatur awal pada kawat adalah 1

To = 1.;
for j =1:ny+1
    T(1,j) = To*(j-1)*dy;
end
for i = 2:nx+1
```

```
    T(i,ny+1) = To*W;
end
for j =1:ny
    for i = 2:nx+1
        T(i,j) = 0.;
    end
end
for i = 1:nx+1
    x(i) = dx*(i-1);
end
for j = 1:ny+1
    y(j) = dy*(j-1);
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Implementasi metode SOR

batas_min_iterasi = (nx)*(ny-1)-(jp-1)*(nx+2-ip);
batas_max_iterasi = 1000;
max = 1;
min = 0;
while ((min<batas_min_iterasi)*(max<batas_max_iterasi))
    min = 0;
    % batas bawah
    for j = 2:jp
        for i=2:ip-1
            TT = rdx2*(T(i+1,j)+T(i-1,j));
            TT = TT + rdy2*(T(i,j+1)+T(i,j-1));
            TT = TT/(2.*rdx2 + 2.*rdy2);
            TT = (1.-omega)*T(i,j) + omega*TT;
            error = abs(TT - T(i,j));
            T(i,j) = TT;
            if (error<eps)
                min = min+1;
            end
        end
    end

    % batas atas
    for j = jp+1:ny
        for i=2:nx
            TT = rdx2*(T(i+1,j)+T(i-1,j));
            TT = TT + rdy2*(T(i,j+1)+T(i,j-1));
            TT = TT/(2.*rdx2 + 2.*rdy2);
            TT = (1.-omega)*T(i,j) + omega*TT;
            error = abs(TT - T(i,j)) ;
            T(i,j) = TT;
            if (error<eps)
                min = min+1;
            end
        end
    end

    % batas kanan
    i = nx+1;
    for j = jp+1:ny
        TT = 2*rdx2*T(i-1,j);
        TT = TT + rdy2*(T(i,j+1)+T(i,j-1));
        TT = TT/(2.*rdx2+2.*rdy2);
        TT = (1.-omega)*T(i,j) + omega*TT;
        error = abs(TT-T(i,j));
        T(i,j) = TT;
        if (error<eps)
            min = min+1;
        end
    end
    max = max+1;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan grafik difusi 2 dimensi bahan sembarang

figure(1)
axis tight
a = mesh(x,y,T');
title 'Difusi Suhu 2 Dimensi Metode SOR'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Temperatur
set(a,'FaceColor','interp','EdgeColor','none','DiffuseStrength',1)
camzoom(1)
view(-35.5,35);
camproj perspective
lightangle(-45,45); colormap(jet(24)); set(gcf,'Renderer','zbuffer');
```

```
colorbar

figure(2)
axis tight
format short
C = contourf(x,y,T(:,:));
clabel(C)
title 'Difusi Suhu 2 Dimensi Metode SOR'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Temperatur

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,:,2500))      % menampilkan data pada t = 2500
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Sembarang Metode SOR');
data = {'(x,:)', T(1,1), T(10,1), T(20,1), T(25,1), T(35,1), T(40,1), T(50,1);
        '(x,:)', T(1,2), T(10,2), T(20,2), T(25,2), T(35,2), T(40,2), T(50,2);
        '(x,:)', T(1,3), T(10,3), T(20,3), T(25,3), T(35,3), T(40,3), T(50,3);
        '(x,:)', T(1,4), T(10,4), T(20,4), T(25,4), T(35,4), T(40,4), T(50,4);
        '(x,:)', T(1,5), T(10,5), T(20,5), T(25,5), T(35,5), T(40,5), T(50,5);
        '(x,:)', T(1,6), T(10,6), T(20,6), T(25,6), T(35,6), T(40,6), T(50,6);
        '(x,:)', T(1,7), T(10,7), T(20,7), T(25,7), T(35,7), T(40,7), T(50,7);
        '(x,:)', T(1,8), T(10,8), T(20,8), T(25,8), T(35,8), T(40,8), T(50,8);
        '(x,:)', T(1,9), T(10,9), T(20,9), T(25,9), T(35,9), T(40,9), T(50,9);
        '(x,:)', T(1,10), T(10,10), T(20,10), T(25,10), T(35,10), T(40,10), T(50,10);
        '(x,:)', T(1,11), T(10,11), T(20,11), T(25,11), T(35,11), T(40,11), T(50,11);
        '(x,:)', T(1,12), T(10,12), T(20,12), T(25,12), T(35,12), T(40,12), T(50,12);
        '(x,:)', T(1,13), T(10,13), T(20,13), T(25,13), T(35,13), T(40,13), T(50,13);
        '(x,:)', T(1,14), T(10,14), T(20,14), T(25,14), T(35,14), T(40,14), T(50,14);
        '(x,:)', T(1,15), T(10,15), T(20,15), T(25,15), T(35,15), T(40,15), T(50,15);
        '(x,:)', T(1,16), T(10,16), T(20,16), T(25,16), T(35,16), T(40,16), T(50,16);
        '(x,:)', T(1,17), T(10,17), T(20,17), T(25,17), T(35,17), T(40,17), T(50,17);
        '(x,:)', T(1,18), T(10,18), T(20,18), T(25,18), T(35,18), T(40,18), T(50,18);
        '(x,:)', T(1,19), T(10,19), T(20,19), T(25,19), T(35,19), T(40,19), T(50,19);
        '(x,:)', T(1,20), T(10,20), T(20,20), T(25,20), T(35,20), T(40,20), T(50,20);
        '(x,:)', T(1,21), T(10,21), T(20,21), T(25,21), T(35,21), T(40,21), T(50,21);
        '(x,:)', T(1,22), T(10,22), T(20,22), T(25,22), T(35,22), T(40,22), T(50,22);
        '(x,:)', T(1,23), T(10,23), T(20,23), T(25,23), T(35,23), T(40,23), T(50,23);
        '(x,:)', T(1,24), T(10,24), T(20,24), T(25,24), T(35,24), T(40,24), T(50,24);
        '(x,:)', T(1,25), T(10,25), T(20,25), T(25,25), T(35,25), T(40,25), T(50,25);
        '(x,:)', T(1,26), T(10,26), T(20,26), T(25,26), T(35,26), T(40,26), T(50,26);
        '(x,:)', T(1,27), T(10,27), T(20,27), T(25,27), T(35,27), T(40,27), T(50,27);
        '(x,:)', T(1,28), T(10,28), T(20,28), T(25,28), T(35,28), T(40,28), T(50,28);
        '(x,:)', T(1,29), T(10,29), T(20,29), T(25,29), T(35,29), T(40,29), T(50,29);
        '(x,:)', T(1,30), T(10,30), T(20,30), T(25,30), T(35,30), T(40,30), T(50,30);
        '(x,:)', T(1,31), T(10,31), T(20,31), T(25,31), T(35,31), T(40,31), T(50,31);
        '(x,:)', T(1,32), T(10,32), T(20,32), T(25,32), T(35,32), T(40,32), T(50,32);
        '(x,:)', T(1,33), T(10,33), T(20,33), T(25,33), T(35,33), T(40,33), T(50,33);
        '(x,:)', T(1,34), T(10,34), T(20,34), T(25,34), T(35,34), T(40,34), T(50,34);
        '(x,:)', T(1,35), T(10,35), T(20,35), T(25,35), T(35,35), T(40,35), T(50,35);
        '(x,:)', T(1,36), T(10,36), T(20,36), T(25,36), T(35,36), T(40,36), T(50,36);
        '(x,:)', T(1,37), T(10,37), T(20,37), T(25,37), T(35,37), T(40,37), T(50,37);
        '(x,:)', T(1,38), T(10,38), T(20,38), T(25,38), T(35,38), T(40,38), T(50,38);
        '(x,:)', T(1,39), T(10,39), T(20,39), T(25,39), T(35,39), T(40,39), T(50,39);
        '(x,:)', T(1,40), T(10,40), T(20,40), T(25,40), T(35,40), T(40,40), T(50,40);
        '(x,:)', T(1,41), T(10,41), T(20,41), T(25,41), T(35,41), T(40,41), T(50,41);
        '(x,:)', T(1,42), T(10,42), T(20,42), T(25,42), T(35,42), T(40,42), T(50,42);
        '(x,:)', T(1,43), T(10,43), T(20,43), T(25,43), T(35,43), T(40,43), T(50,43);
        '(x,:)', T(1,44), T(10,44), T(20,44), T(25,44), T(35,44), T(40,44), T(50,44);
        '(x,:)', T(1,45), T(10,45), T(20,45), T(25,45), T(35,45), T(40,45), T(50,45);
        '(x,:)', T(1,46), T(10,46), T(20,46), T(25,46), T(35,46), T(40,46), T(50,46);
        '(x,:)', T(1,47), T(10,47), T(20,47), T(25,47), T(35,47), T(40,47), T(50,47);
        '(x,:)', T(1,48), T(10,48), T(20,48), T(25,48), T(35,48), T(40,48), T(50,48);
        '(x,:)', T(1,49), T(10,49), T(20,49), T(25,49), T(35,49), T(40,49), T(50,49);
        '(x,:)', T(1,50), T(10,50), T(20,50), T(25,50), T(35,50), T(40,50), T(50,50);
        '(x,:)', T(1,51), T(10,51), T(20,51), T(25,51), T(35,51), T(40,51), T(50,51);};

columnname = {'Sumbu-
xy','T(x(1),:)','T(x(10),:)','T(x(20),:)','T(x(25),:)','T(x(35),y:)',...
    'T(x(40),:)','T(x(50),:)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Distribusi suhu analitik 3 dimensi pada bahan Aluminium
% T(t,x,y,z) = exp(-3*(pi^2)*t)*sin(pi(x))*sin(pi(y))*sin(pi(z))
% Kondisi awal T0(x,y,z) = sin(pi*(x))*sin(pi(y))*sin(pi(z))
% Bahan Aluminium difusivitas 0.000971348 ~ 0.000971
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% inisialisasi parameter masukan

p = 1.;                 % panjang x
q = p;                  % panjang y
r = q;                  % panjang z
x = [0:p/25:p];         % lebar grid x
y = x;                  % lebar grid y
z = y;                  % lebar grid z
t = [0:1:1500];         % waktu iterasi 0 sampai dengan 1500
dif = 0.000971;         % difusivitas bahan Aluiminium
%T0 = sin(pi*x/25).*sin(pi*y/25).*sin(pi*z/25);     % temperatur awal

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menggunkan persamaan difusi 3 dimensi analitik

for n = 1:max(size(t))
     for k = 1:max(size(z))
        for j = 1:max(size(y))
            for i = 1:max(size(x))
                T(i,j,k,n) = exp(-3.*dif.*(pi.^2)*t(n)/p.^2)...
                    .*sin(pi.*(x(i))/p).*sin(pi.*(y(j))/q)...
                    .*sin(pi.*(z(k))/r);
            end
        end
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik difusi 3 dimensi analitik

%figure(1)
%u = T(:,:,:,ci);
%slice(x,y,z,ci,[3 5],[2 5],[0 3])
%axis tight

figure(2)
axis tight
v = T(:,:,:,n);
a = slice(x,y,z,v,.75,[.4 .9],.1);
title 'Difusi Suhu Bahan Aluminium 3 Dimensi Aluminium Analitik'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Sumbu-z
set(a,'FaceColor','interp','EdgeColor','none','DiffuseStrength',1)
daspect([0.1,0.1,0.1]);box on; view(-38.5,16);
camzoom(1)
camproj perspective
lightangle(-45,45); colormap(jet(24)); set(gcf,'Renderer','zbuffer');
colorbar
hold off

figure(3)
a = squeeze(v); contourslice(a,[],[],[1 10 15 20],400); view(3);
axis tight
title 'Difusi Suhu Bahan Aluminium 3 Dimensi Aluminium Analitik'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Sumbu-z

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,:,:,1500))     % menampilkan data pada t = 1500
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Aluminium 3 Dimensi
Analitik');
data = {'(1,1,1)', T(1,2,2,2), T(1,10,10,50), T(1,12,12,100), T(1,15,15,500),
T(1,20,20,1000), T(1,25,25,1500);
        '(2,2,2)', T(2,2,2,2), T(2,10,10,50), T(2,12,12,100), T(2,15,15,500),
T(2,20,20,1000), T(2,25,25,1500);
        '(3,3,3)', T(3,2,2,2), T(3,10,10,50), T(3,12,12,100), T(3,15,15,500),
T(3,20,20,1000), T(3,25,25,1500);
        '(4,4,4)', T(4,2,2,2), T(4,10,10,50), T(4,12,12,100), T(4,15,15,500),
T(4,20,20,1000), T(4,25,25,1500);
        '(5,5,5)', T(5,2,2,2), T(5,10,10,50), T(5,12,12,100), T(5,15,15,500),
T(5,20,20,1000), T(5,25,25,1500);
```

```
        '(6,6,6)', T(6,2,2,2), T(6,10,10,50), T(6,12,12,100), T(6,15,15,500),
T(6,20,20,1000), T(6,25,25,1500);
        '(7,7,7)', T(7,2,2,2), T(7,10,10,50), T(7,12,12,100), T(7,15,15,500),
T(7,20,20,1000), T(7,25,25,1500);
        '(8,8,8)', T(8,2,2,2), T(8,10,10,50), T(8,12,12,100), T(8,15,15,500),
T(8,20,20,1000), T(8,25,25,1500);
        '(9,9,8)', T(9,2,2,2), T(9,10,10,50), T(9,12,12,100), T(9,15,15,500),
T(9,20,20,1000), T(9,25,25,1500);
        '(10,10,10)', T(10,2,2,2), T(10,10,10,50), T(10,12,12,100), T(10,15,15,500),
T(10,20,20,1000), T(10,25,25,1500);
        '(11,11,11)', T(11,2,2,2), T(11,10,10,50), T(11,12,12,100), T(11,15,15,500),
T(11,20,20,1000), T(11,25,25,1500);
        '(12,12,12)', T(12,2,2,2), T(12,10,10,50), T(12,12,12,100), T(12,15,15,500),
T(12,20,20,1000), T(12,25,25,1500);
        '(13,13,13)', T(13,2,2,2), T(13,10,10,50), T(13,12,12,100), T(13,15,15,500),
T(13,20,20,1000), T(13,25,25,1500);
        '(14,14,14)', T(14,2,2,2), T(14,10,10,50), T(14,12,12,100), T(14,15,15,500),
T(14,20,20,1000), T(14,25,25,1500);
        '(15,15,15)', T(15,2,2,2), T(15,10,10,50), T(15,12,12,100), T(15,15,15,500),
T(15,20,20,1000), T(15,25,25,1500);
        '(16,16,16)', T(16,2,2,2), T(16,10,10,50), T(16,12,12,100), T(16,15,15,500),
T(16,20,20,1000), T(16,25,25,1500);
        '(17,17,17)', T(17,2,2,2), T(17,10,10,50), T(17,12,12,100), T(17,15,15,500),
T(17,20,20,1000), T(17,25,25,1500);
        '(18,18,18)', T(18,2,2,2), T(18,10,10,50), T(18,12,12,100), T(18,15,15,500),
T(18,20,20,1000), T(18,25,25,1500);
        '(19,19,19)', T(19,2,2,2), T(19,10,10,50), T(19,12,12,100), T(19,15,15,500),
T(19,20,20,1000), T(19,25,25,1500);
        '(20,20,20)', T(20,2,2,2), T(20,10,10,50), T(20,12,12,100), T(20,15,15,500),
T(20,20,20,1000), T(20,25,25,1500);
        '(21,21,21)', T(21,2,2,2), T(21,10,10,50), T(21,12,12,100), T(21,15,15,500),
T(21,20,20,1000), T(21,25,25,1500);
        '(22,22,22)', T(22,2,2,2), T(22,10,10,50), T(22,12,12,100), T(22,15,15,500),
T(22,20,20,1000), T(22,25,25,1500);
        '(23,23,23)', T(23,2,2,2), T(23,10,10,50), T(23,12,12,100), T(23,15,15,500),
T(23,20,20,1000), T(23,25,25,1500);
        '(24,24,24)', T(24,2,2,2), T(24,10,10,50), T(24,12,12,100), T(24,15,15,500),
T(24,20,20,1000), T(24,25,25,1500);
        '(25,25,25)', T(25,2,2,2), T(25,10,10,50), T(25,12,12,100), T(25,15,15,500),
T(25,20,20,1000), T(25,25,25,1500);
        '(26,26,26)', T(26,2,2,2), T(26,10,10,50), T(26,12,12,100), T(26,15,15,500),
T(26,20,20,1000), T(26,25,25,1500);};

columnname = {'Sumbu-xyz','T(x,y,z,2)','T(x,y,z,50)','T(x,y,z,100)','T(x,y,z,500)',...
    'T(x,y,z,1000)','T(x,y,z,1500)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Distribusi suhu analitik 3 dimensi pada bahan Perak
% T(t,x,y,z) = exp(-3*(pi^2)*t)*sin(pi(x))*sin(pi(y))*sin(pi(z))
% Kondisi awal T0(x,y,z) = sin(pi*(x))*sin(pi(y))*sin(pi(z))
% Bahan Perak difusivitas 0.00173860182 ~ 0.00174
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% inisialisasi parameter masukan

p = 1.;                 % panjang x
q = p;                  % panjang y
r = q;                  % panjang z
x = [0:p/25:p];         % lebar grid x
y = x;                  % lebar grid y
z = y;                  % lebar grid z
t = [0:1:1500];         % waktu iterasi 0 sampai dengan 1500
dif = 0.00174;          % difusivitas bahan perak
%ci = sin(pi*x/25).*sin(pi*y/25).*sin(pi*z/25);     % temperatur awal

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menggunkan persamaan difusi 3 dimensi analitik

for n = 1:max(size(t))
     for k = 1:max(size(z))
        for j = 1:max(size(y))
            for i = 1:max(size(x))
                T(i,j,k,n) = exp(-3.*dif.*(pi.^2)*t(n)/p.^2)...
```

```
                    .*sin(pi.*(x(i))/p).*sin(pi.*(y(j))/q)...
                    .*sin(pi.*(z(k))/r);
            end
        end
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%figure(1)
%u = T(:,:,:,ci);
%slice(x,y,z,ci,[3 5],[2 5],[0 3])
%axis tight

% menampilkan grafik difusi 3 dimensi analitik
figure(2)
axis tight
v = T(:,:,:,n);
a = slice(x,y,z,v,.75,[.4 .9],.1);
title 'Difusi Suhu Bahan Perak 3 Dimensi Analitik'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Sumbu-z
set(a,'FaceColor','interp','EdgeColor','none','DiffuseStrength',1)
daspect([0.1,0.1,0.1]);box on; view(-38.5,16);
camzoom(1)
camproj perspective
lightangle(-45,45); colormap(jet(24)); set(gcf,'Renderer','zbuffer');
colorbar
hold off

figure(3)
a = squeeze(v); contourslice(a,[],[],[1 10 15 20],400); view(3);
axis tight
title 'Difusi Suhu Bahan Perak 3 Dimensi Analitik'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Sumbu-z

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,:,1500))     % menampilkan data pada t = 1500
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Perak 3 Dimensi
Analitik');
data = {'(1,1,1)', T(1,2,2,2), T(1,10,10,50), T(1,12,12,100), T(1,15,15,500),
T(1,20,20,1000), T(1,25,25,1500);
        '(2,2,2)', T(2,2,2,2), T(2,10,10,50), T(2,12,12,100), T(2,15,15,500),
T(2,20,20,1000), T(2,25,25,1500);
        '(3,3,3)', T(3,2,2,2), T(3,10,10,50), T(3,12,12,100), T(3,15,15,500),
T(3,20,20,1000), T(3,25,25,1500);
        '(4,4,4)', T(4,2,2,2), T(4,10,10,50), T(4,12,12,100), T(4,15,15,500),
T(4,20,20,1000), T(4,25,25,1500);
        '(5,5,5)', T(5,2,2,2), T(5,10,10,50), T(5,12,12,100), T(5,15,15,500),
T(5,20,20,1000), T(5,25,25,1500);
        '(6,6,6)', T(6,2,2,2), T(6,10,10,50), T(6,12,12,100), T(6,15,15,500),
T(6,20,20,1000), T(6,25,25,1500);
        '(7,7,7)', T(7,2,2,2), T(7,10,10,50), T(7,12,12,100), T(7,15,15,500),
T(7,20,20,1000), T(7,25,25,1500);
        '(8,8,8)', T(8,2,2,2), T(8,10,10,50), T(8,12,12,100), T(8,15,15,500),
T(8,20,20,1000), T(8,25,25,1500);
        '(9,9,8)', T(9,2,2,2), T(9,10,10,50), T(9,12,12,100), T(9,15,15,500),
T(9,20,20,1000), T(9,25,25,1500);
        '(10,10,10)', T(10,2,2,2), T(10,10,10,50), T(10,12,12,100), T(10,15,15,500),
T(10,20,20,1000), T(10,25,25,1500);
        '(11,11,11)', T(11,2,2,2), T(11,10,10,50), T(11,12,12,100), T(11,15,15,500),
T(11,20,20,1000), T(11,25,25,1500);
        '(12,12,12)', T(12,2,2,2), T(12,10,10,50), T(12,12,12,100), T(12,15,15,500),
T(12,20,20,1000), T(12,25,25,1500);
        '(13,13,13)', T(13,2,2,2), T(13,10,10,50), T(13,12,12,100), T(13,15,15,500),
T(13,20,20,1000), T(13,25,25,1500);
        '(14,14,14)', T(14,2,2,2), T(14,10,10,50), T(14,12,12,100), T(14,15,15,500),
T(14,20,20,1000), T(14,25,25,1500);
        '(15,15,15)', T(15,2,2,2), T(15,10,10,50), T(15,12,12,100), T(15,15,15,500),
T(15,20,20,1000), T(15,25,25,1500);
        '(16,16,16)', T(16,2,2,2), T(16,10,10,50), T(16,12,12,100), T(16,15,15,500),
T(16,20,20,1000), T(16,25,25,1500);
        '(17,17,17)', T(17,2,2,2), T(17,10,10,50), T(17,12,12,100), T(17,15,15,500),
T(17,20,20,1000), T(17,25,25,1500);
        '(18,18,18)', T(18,2,2,2), T(18,10,10,50), T(18,12,12,100), T(18,15,15,500),
T(18,20,20,1000), T(18,25,25,1500);
        '(19,19,19)', T(19,2,2,2), T(19,10,10,50), T(19,12,12,100), T(19,15,15,500),
T(19,20,20,1000), T(19,25,25,1500);
```

```
        '(20,20,20)', T(20,2,2,2), T(20,10,10,50), T(20,12,12,100), T(20,15,15,500),
T(20,20,20,1000), T(20,25,25,1500);
        '(21,21,21)', T(21,2,2,2), T(21,10,10,50), T(21,12,12,100), T(21,15,15,500),
T(21,20,20,1000), T(21,25,25,1500);
        '(22,22,22)', T(22,2,2,2), T(22,10,10,50), T(22,12,12,100), T(22,15,15,500),
T(22,20,20,1000), T(22,25,25,1500);
        '(23,23,23)', T(23,2,2,2), T(23,10,10,50), T(23,12,12,100), T(23,15,15,500),
T(23,20,20,1000), T(23,25,25,1500);
        '(24,24,24)', T(24,2,2,2), T(24,10,10,50), T(24,12,12,100), T(24,15,15,500),
T(24,20,20,1000), T(24,25,25,1500);
        '(25,25,25)', T(25,2,2,2), T(25,10,10,50), T(25,12,12,100), T(25,15,15,500),
T(25,20,20,1000), T(25,25,25,1500);
        '(26,26,26)', T(26,2,2,2), T(26,10,10,50), T(26,12,12,100), T(26,15,15,500),
T(26,20,20,1000), T(26,25,25,1500);};

columnname = {'Sumbu-xyz','T(x,y,z,2)','T(x,y,z,50)','T(x,y,z,100)','T(x,y,z,500)',...
    'T(x,y,z,1000)','T(x,y,z,1500)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Distribusi suhu numerik 3 dimensi pada bahan Aluminium
% Metode ini menggunakan metode beda hingga
% Skema yang digunakan adalah skema Eksplisit (FTCS)
% Bahan Aluminium difusivitas 0.000971348 ~ 0.000971
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% inisialisasi parameter masukan

L = 1.0;                        % panjang x
W = L;                          % panjang y
T = W;                          % panjang z
Tend = 356.2;                   % waktu akhir
Tmax_step = 1500.;              % waktu step
nmax_step = 25.;                % jarak step
dt = Tend/Tmax_step;            % delta t
dx = L/nmax_step;               % delta x
dy = dx;                        % delta y
dz = dy;                        % delta y

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% sifat fisis bahan

% kond = 237;                       % konduktivitas bahan
% Cp = 903;                         % panas spesifik bahan
% rho = 2702.;                      % massa jenis bahan
dif = 0.000971;                     % difusivitas = cond/(spheat*rho);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% parameter masukan nilai r

r = dif*dt/(dx.^2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% kondisi awal

for i = 1:nmax_step+1
    x(i) = (i-1)*dx;
    y(i) = (i-1)*dy;
    z(i) = (i-1)*dz;
    T(1:nmax_step+1,1:nmax_step+1,1:nmax_step+1,Tmax_step+1) = ...
        sin(pi*(x(i)))*sin(pi*(y(i)))*sin(pi*(z(i)));
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% kondisi batas

for n = 1:Tmax_step+1
    for k = 1:nmax_step+1
        for j = 1:nmax_step+1
            for i = 1:nmax_step+1
                T(n) = (n-1)*dt;
                T(1,1,1:nmax_step+1,n) = 0;
                T(1,1:nmax_step+1,1,n) = 0;
                T(1:nmax_step+1,1,1,n) = 0;
```

```
                T(nmax_step+1,1,1:nmax_step+1,n) = 0;
                T(nmax_step+1,1:nmax_step+1,1,n) = 0;
                T(1:nmax_step+1,nmax_step+1,1,n) = 0;
                T(1,nmax_step+1,1:nmax_step+1,n) = 0;
                T(1,1:nmax_step+1,nmax_step+1,n) = 0;
                T(1:nmax_step+1,1,nmax_step+1,n) = 0;
                T(nmax_step+1,nmax_step+1,1:nmax_step+1,n) = 0;
                T(nmax_step+1,1:nmax_step+1,nmax_step+1,n) = 0;
                T(1:nmax_step+1,nmax_step+1,nmax_step+1,n) = 0;
            end
        end
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% metode FTCS

for n = 1:Tmax_step
    for k = 2:nmax_step
        for j = 2:nmax_step
            for i = 2:nmax_step
                T(i,j,k,n+1) = T(i,j,k,n)+r*(T(i-1,j,k,n)+T(i+1,j,k,n)+...
                    T(i,j-1,k,n)+T(i,j+1,k,n)+T(i,j,k-1,n)+T(i,j,k+1,n)...
                    -6*T(i,j,k,n));
            end
        end
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik difusi 3 dimensi

figure(1)
v = T(:,:,:,n);
T(n)                                    % menghitung nilai iterasi
axis tight
dif = slice(x,y,z,v,.75,[.4 .9],.1);      % menampilkan grafik 3 dimensi
colorbar vert                           % menampilkan colorbar
title 'Difusi Suhu Bahan Aluminium 3 Dimensi Aluminium Metode FTCS'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Sumbu-z
set(dif,'FaceColor','interp','EdgeColor','none','DiffuseStrength',1)
daspect([0.1,0.1,0.1]);box on; view(-38.5,16);
camzoom(1)
camproj perspective
lightangle(-45,45); colormap(jet(24)); set(gcf,'Renderer','zbuffer');
colorbar

figure(2)
dif = squeeze(v); contourslice(dif,[],[],[1 10 15 20],400); view(3);
axis tight
title 'Difusi Suhu Bahan Aluminium 3 Dimensi Aluminium Metode FTCS'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Sumbu-z

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3.6f \n',T(:,:,2500))      % menampilkan data pada t = 2500
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Aluminium 3 Dimensi
Metode FTCS');
data = {'(1,1,1)', T(1,2,2,2), T(1,10,10,50), T(1,12,12,100), T(1,15,15,500),
T(1,20,20,1000), T(1,25,25,1500);
        '(2,2,2)', T(2,2,2,2), T(2,10,10,50), T(2,12,12,100), T(2,15,15,500),
T(2,20,20,1000), T(2,25,25,1500);
        '(3,3,3)', T(3,2,2,2), T(3,10,10,50), T(3,12,12,100), T(3,15,15,500),
T(3,20,20,1000), T(3,25,25,1500);
        '(4,4,4)', T(4,2,2,2), T(4,10,10,50), T(4,12,12,100), T(4,15,15,500),
T(4,20,20,1000), T(4,25,25,1500);
        '(5,5,5)', T(5,2,2,2), T(5,10,10,50), T(5,12,12,100), T(5,15,15,500),
T(5,20,20,1000), T(5,25,25,1500);
        '(6,6,6)', T(6,2,2,2), T(6,10,10,50), T(6,12,12,100), T(6,15,15,500),
T(6,20,20,1000), T(6,25,25,1500);
        '(7,7,7)', T(7,2,2,2), T(7,10,10,50), T(7,12,12,100), T(7,15,15,500),
T(7,20,20,1000), T(7,25,25,1500);
        '(8,8,8)', T(8,2,2,2), T(8,10,10,50), T(8,12,12,100), T(8,15,15,500),
T(8,20,20,1000), T(8,25,25,1500);
        '(9,9,8)', T(9,2,2,2), T(9,10,10,50), T(9,12,12,100), T(9,15,15,500),
T(9,20,20,1000), T(9,25,25,1500);
        '(10,10,10)', T(10,2,2,2), T(10,10,10,50), T(10,12,12,100), T(10,15,15,500),
T(10,20,20,1000), T(10,25,25,1500);
```

```
        '(11,11,11)', T(11,2,2,2), T(11,10,10,50), T(11,12,12,100), T(11,15,15,500),
T(11,20,20,1000), T(11,25,25,1500);
        '(12,12,12)', T(12,2,2,2), T(12,10,10,50), T(12,12,12,100), T(12,15,15,500),
T(12,20,20,1000), T(12,25,25,1500);
        '(13,13,13)', T(13,2,2,2), T(13,10,10,50), T(13,12,12,100), T(13,15,15,500),
T(13,20,20,1000), T(13,25,25,1500);
        '(14,14,14)', T(14,2,2,2), T(14,10,10,50), T(14,12,12,100), T(14,15,15,500),
T(14,20,20,1000), T(14,25,25,1500);
        '(15,15,15)', T(15,2,2,2), T(15,10,10,50), T(15,12,12,100), T(15,15,15,500),
T(15,20,20,1000), T(15,25,25,1500);
        '(16,16,16)', T(16,2,2,2), T(16,10,10,50), T(16,12,12,100), T(16,15,15,500),
T(16,20,20,1000), T(16,25,25,1500);
        '(17,17,17)', T(17,2,2,2), T(17,10,10,50), T(17,12,12,100), T(17,15,15,500),
T(17,20,20,1000), T(17,25,25,1500);
        '(18,18,18)', T(18,2,2,2), T(18,10,10,50), T(18,12,12,100), T(18,15,15,500),
T(18,20,20,1000), T(18,25,25,1500);
        '(19,19,19)', T(19,2,2,2), T(19,10,10,50), T(19,12,12,100), T(19,15,15,500),
T(19,20,20,1000), T(19,25,25,1500);
        '(20,20,20)', T(20,2,2,2), T(20,10,10,50), T(20,12,12,100), T(20,15,15,500),
T(20,20,20,1000), T(20,25,25,1500);
        '(21,21,21)', T(21,2,2,2), T(21,10,10,50), T(21,12,12,100), T(21,15,15,500),
T(21,20,20,1000), T(21,25,25,1500);
        '(22,22,22)', T(22,2,2,2), T(22,10,10,50), T(22,12,12,100), T(22,15,15,500),
T(22,20,20,1000), T(22,25,25,1500);
        '(23,23,23)', T(23,2,2,2), T(23,10,10,50), T(23,12,12,100), T(23,15,15,500),
T(23,20,20,1000), T(23,25,25,1500);
        '(24,24,24)', T(24,2,2,2), T(24,10,10,50), T(24,12,12,100), T(24,15,15,500),
T(24,20,20,1000), T(24,25,25,1500);
        '(25,25,25)', T(25,2,2,2), T(25,10,10,50), T(25,12,12,100), T(25,15,15,500),
T(25,20,20,1000), T(25,25,25,1500);
        '(26,26,26)', T(26,2,2,2), T(26,10,10,50), T(26,12,12,100), T(26,15,15,500),
T(26,20,20,1000), T(26,25,25,1500);};

columnname = {'Sumbu-xyz','T(x,y,z,2)','T(x,y,z,50)','T(x,y,z,100)','T(x,y,z,500)',...
    'T(x,y,z,1000)','T(x,y,z,1500)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'long'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Distribusi panas numerik 3 dimensi pada bahan Perak
% Metode ini menggunakan metode beda hingga
% Skema yang digunakan adalah skema Eksplisit (FTCS)
% Bahan Perak difusivitas 0.00173860182 ~ 0.00174
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% inisialisasi parameter masukan

L = 1.0;                        % panjang x
W = L;                          % panjang y
T = W;                          % panjang z
Tend = 227.3 ;                  % waktu akhir
Tmax_step = 1500.;              % waktu step
nmax_step = 25.;                % jarak step
dt = Tend/Tmax_step;            % delta t
dx = L/nmax_step;               % delta x
dy = dx;                        % delta y
dz = dy;                        % delta z

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% sifat fisis bahan

% kond = 429.;                  % konduktivitas bahan
% Cp = 235.;                    % panas spesifik
% rho = 10500.;                 % massa jenis bahan
dif = 0.00174;                  % difusivitas cond/(spheat*rho);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% parameter masukan nilai r

r = dif*dt/(dx.^2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% kondisi awal

for i = 1:nmax_step+1
```

```
    x(i) = (i-1)*dx;
    y(i) = (i-1)*dy;
    z(i) = (i-1)*dz;
    T(1:nmax_step+1,1:nmax_step+1,1:nmax_step+1,1) = ...
        sin(pi*(x(i)))*sin(pi*(y(i)))*sin(pi*(z(i)));
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% kondisi batas
for n = 1:Tmax_step+1
    for k = 1:nmax_step+1
        for j = 1:nmax_step+1
            for i = 1:nmax_step+1
                T(n) = (n-1)*dt;
                T(1,1,1:nmax_step+1,n) = 0;
                T(1,1:nmax_step+1,1,n) = 0;
                T(1:nmax_step+1,1,1,n) = 0;
                T(nmax_step+1,1,1:nmax_step+1,n) = 0;
                T(nmax_step+1,1:nmax_step+1,1,n) = 0;
                T(1:nmax_step+1,nmax_step+1,1,n) = 0;
                T(1,nmax_step+1,1:nmax_step+1,n) = 0;
                T(1,1:nmax_step+1,nmax_step+1,n) = 0;
                T(1:nmax_step+1,1,nmax_step+1,n) = 0;
                T(nmax_step+1,nmax_step+1,1:nmax_step+1,n) = 0;
                T(nmax_step+1,1:nmax_step+1,nmax_step+1,n) = 0;
                T(1:nmax_step+1,nmax_step+1,nmax_step+1,n) = 0;
            end
        end
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% metode FTCS

for n = 1:Tmax_step
    for k = 2:nmax_step
        for j = 2:nmax_step
            for i = 2:nmax_step
                T(i,j,k,n+1) = T(i,j,k,n)+r*(T(i-1,j,k,n)+T(i+1,j,k,n)+...
                    T(i,j-1,k,n)+T(i,j+1,k,n)+T(i,j,k-1,n)+T(i,j,k+1,n)...
                    -6*T(i,j,k,n));
            end
        end
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik difusi 3 dimensi

figure(1)
v = T(:,:,:,n);
T(n)                                    % menghitung nilai iterasi
axis tight
dif = slice(x,y,z,v,.75,[.4 .9],.1);    % menampilkan grafik 3 dimensi
colorbar vert                           % menampilkan colorbar
title 'Difusi Suhu Bahan Perak 3 Dimensi Metode FTCS'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Sumbu-z
set(dif,'FaceColor','interp','EdgeColor','none','DiffuseStrength',1)
daspect([0.1,0.1,0.1]);box on; view(-38.5,16);
camzoom(1)
camproj perspective
lightangle(-45,45); colormap(jet(24)); set(gcf,'Renderer','zbuffer');
colorbar

figure(2)
dif = squeeze(v); contourslice(dif,[],[],[1 10 15 20],400); view(3);
axis tight
title 'Difusi Suhu Bahan Perak 3 Dimensi Metode FTCS'
xlabel Sumbu-x
ylabel Sumbu-y
zlabel Sumbu-z

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Menampilkan data

hold off
%fprintf('%3t.6f \n',T(:,:,1500))     % menampilkan data pada t = 1500
f = figure('Position',[200 200 500 200],'Name','Difusi Suhu Bahan Perak 3 Dimensi Metode
FTCS');
data = {'(1,1,1)', T(1,2,2,2), T(1,10,10,50), T(1,12,12,100), T(1,15,15,500),
T(1,20,20,1000), T(1,25,25,1500);
```

```
        '(2,2,2)', T(2,2,2,2), T(2,10,10,50), T(2,12,12,100), T(2,15,15,500),
T(2,20,20,1000), T(2,25,25,1500);
        '(3,3,3)', T(3,2,2,2), T(3,10,10,50), T(3,12,12,100), T(3,15,15,500),
T(3,20,20,1000), T(3,25,25,1500);
        '(4,4,4)', T(4,2,2,2), T(4,10,10,50), T(4,12,12,100), T(4,15,15,500),
T(4,20,20,1000), T(4,25,25,1500);
        '(5,5,5)', T(5,2,2,2), T(5,10,10,50), T(5,12,12,100), T(5,15,15,500),
T(5,20,20,1000), T(5,25,25,1500);
        '(6,6,6)', T(6,2,2,2), T(6,10,10,50), T(6,12,12,100), T(6,15,15,500),
T(6,20,20,1000), T(6,25,25,1500);
        '(7,7,7)', T(7,2,2,2), T(7,10,10,50), T(7,12,12,100), T(7,15,15,500),
T(7,20,20,1000), T(7,25,25,1500);
        '(8,8,8)', T(8,2,2,2), T(8,10,10,50), T(8,12,12,100), T(8,15,15,500),
T(8,20,20,1000), T(8,25,25,1500);
        '(9,9,8)', T(9,2,2,2), T(9,10,10,50), T(9,12,12,100), T(9,15,15,500),
T(9,20,20,1000), T(9,25,25,1500);
        '(10,10,10)', T(10,2,2,2), T(10,10,10,50), T(10,12,12,100), T(10,15,15,500),
T(10,20,20,1000), T(10,25,25,1500);
        '(11,11,11)', T(11,2,2,2), T(11,10,10,50), T(11,12,12,100), T(11,15,15,500),
T(11,20,20,1000), T(11,25,25,1500);
        '(12,12,12)', T(12,2,2,2), T(12,10,10,50), T(12,12,12,100), T(12,15,15,500),
T(12,20,20,1000), T(12,25,25,1500);
        '(13,13,13)', T(13,2,2,2), T(13,10,10,50), T(13,12,12,100), T(13,15,15,500),
T(13,20,20,1000), T(13,25,25,1500);
        '(14,14,14)', T(14,2,2,2), T(14,10,10,50), T(14,12,12,100), T(14,15,15,500),
T(14,20,20,1000), T(14,25,25,1500);
        '(15,15,15)', T(15,2,2,2), T(15,10,10,50), T(15,12,12,100), T(15,15,15,500),
T(15,20,20,1000), T(15,25,25,1500);
        '(16,16,16)', T(16,2,2,2), T(16,10,10,50), T(16,12,12,100), T(16,15,15,500),
T(16,20,20,1000), T(16,25,25,1500);
        '(17,17,17)', T(17,2,2,2), T(17,10,10,50), T(17,12,12,100), T(17,15,15,500),
T(17,20,20,1000), T(17,25,25,1500);
        '(18,18,18)', T(18,2,2,2), T(18,10,10,50), T(18,12,12,100), T(18,15,15,500),
T(18,20,20,1000), T(18,25,25,1500);
        '(19,19,19)', T(19,2,2,2), T(19,10,10,50), T(19,12,12,100), T(19,15,15,500),
T(19,20,20,1000), T(19,25,25,1500);
        '(20,20,20)', T(20,2,2,2), T(20,10,10,50), T(20,12,12,100), T(20,15,15,500),
T(20,20,20,1000), T(20,25,25,1500);
        '(21,21,21)', T(21,2,2,2), T(21,10,10,50), T(21,12,12,100), T(21,15,15,500),
T(21,20,20,1000), T(21,25,25,1500);
        '(22,22,22)', T(22,2,2,2), T(22,10,10,50), T(22,12,12,100), T(22,15,15,500),
T(22,20,20,1000), T(22,25,25,1500);
        '(23,23,23)', T(23,2,2,2), T(23,10,10,50), T(23,12,12,100), T(23,15,15,500),
T(23,20,20,1000), T(23,25,25,1500);
        '(24,24,24)', T(24,2,2,2), T(24,10,10,50), T(24,12,12,100), T(24,15,15,500),
T(24,20,20,1000), T(24,25,25,1500);
        '(25,25,25)', T(25,2,2,2), T(25,10,10,50), T(25,12,12,100), T(25,15,15,500),
T(25,20,20,1000), T(25,25,25,1500);
        '(26,26,26)', T(26,2,2,2), T(26,10,10,50), T(26,12,12,100), T(26,15,15,500),
T(26,20,20,1000), T(26,25,25,1500);};

columnname = {'Sumbu-xyz','T(x,y,z,2)','T(x,y,z,50)','T(x,y,z,100)','T(x,y,z,500)',...
    'T(x,y,z,1000)','T(x,y,z,1500)'};
columnformat = {'numeric', 'long', 'long', 'long', 'long', 'long', 'short'};
t = uitable('Units','normalized','Position',[0.09 0.009 .8 .8],...
            'Data', data,'ColumnName', columnname,...
            'ColumnFormat', columnformat,'RowName',[]);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Perbandingan difusi panas hasil analitik dan numerik bahan Aluminium dan
% bahan Perak 1 dimensi.
% Difusi panas pada T(x,t) dengan x = 1 sampai dengan 51 dan t = 1 sampai
% dengan 295000.
% Data yang dtampilkan di bawah ini adalah data pada t = 5000, nilai x
% berubah dari 1 sampai dengan 51 sedangkan t adalah tetap.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% hasil nilai analitik bahan Aluminium 1 dimensi pada x = 1 sampai dengan 51
% dan t = 5000

Alum1D_analitik = [0.0000000000000000
0.0606709345159280
0.1211024285712360
0.1810559866674100
0.2402949995008190
0.2985856777515420
0.3556979747430000
0.4114064943310950
0.4654913804398130
0.5177391847327180
0.5679437089960180
0.6159068189087100
0.6614392259882290
0.7043612346256110
0.7445034512619650
0.7817074529074610
0.8158264123644950
```

```
0.8467256776875620
0.8742833035929620
0.8983905327211280
0.9189522248522370
0.9358872323811900
0.9491287205701420
0.9586244313146690
0.9643368893826410
0.9662435503118370
0.9643368893826410
0.9586244313146690
0.9491287205701420
0.9358872323811900
0.9189522248522370
0.8983905327211280
0.8742833035929610
0.8467256776875620
0.8158264123644950
0.7817074529074610
0.7445034512619650
0.7043612346256110
0.6614392259882290
0.6159068189087100
0.5679437089960180
0.5177391847327190
0.4654913804398130
0.4114064943310950
0.3556979747430000
0.2985856777515420
0.2402949995008200
0.1810559866674100
0.1211024285712360
0.0606709345159290
0.0000000000000001];

% hasil nilai numerik bahan Aluminium 1 dimensi pada x = 1 sampai dengan 51
% dan t = 5000

Alum1D_numerik = [0.0000000000000000
0.0606363294490050
0.1210333550077800
0.1809527172092180
0.2401579417052670
0.2984153725231350
0.3554950941986720
0.4111718391476680
0.4652258766940910
0.5174438802466840
0.5676197692015830
0.6155555222482240
0.6610619588691140
0.7039594859488390
0.7440788065460430
0.7812615880310540
0.8153610869525630
0.8462427281669170
0.8737846359447270
0.8978781149586990
0.9184280792544290
0.9353534275112260
0.9485873631119750
0.9580776577588750
0.9637868575946470
0.9656924310158270
0.9637868575946820
0.9580776577589180
0.9485873631120490
0.9353534275113270
0.9184280792545450
0.8978781149587990
0.8737846359448180
0.8462427281669840
0.8153610869526270
0.7812615880311010
0.7440788065460960
0.7039594859489040
0.6610619588691580
0.6155555222482240
0.5676197692015720
0.5174438802466770
0.4652258766940850
0.4111718391476620
0.3554950941986720
0.2984153725231430
0.2401579417052810
0.1809527172092360
0.1210333550077980
0.0606363294490170
0.0000000000000000];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% hasil nilai analitik bahan Perak 1 dimensi pada x = 1 sampai dengan 51
% dan t = 5000

Per1D_analitik = [0.0000000000000000
0.0615987242918120
0.1229543465606240
0.1838247241960590
0.2439696296266200
0.3031516983881670
0.3611373658930130
0.4176977892026470
0.4726097501662670
0.5256565363608370
0.5766287963560180
0.6253253659286220
0.6715540619658900
0.7151324409244460
0.7558885188516080
0.7936614501274780
0.8283021622491220
0.8596739441516310
0.8876529857442390
0.9121288665321900
0.9330049913959790
0.9501989718081640
0.9636429509832390
0.9732838716773700
```

```
0.9790836855810960
0.9810195034786220
0.9790836855810960
0.9732838716773700
0.9636429509832390
0.9501989718081640
0.9330049913959790
0.9121288665321900
0.8876529857442390
0.8596739441516310
0.8283021622491220
0.7936614501274780
0.7558885188516080
0.7151324409244460
0.6715540619658900
0.6253253659286220
0.5766287963560190
0.5256565363608370
0.4726097501662660
0.4176977892026470
0.3611373658930130
0.3031516983881670
0.2439696296266210
0.1838247241960590
0.1229543465606240
0.0615987242918120
0.0000000000000001];

% hasil nilai numerik bahan Perak 1 dimensi pada x = 1 sampai dengan 51
% dan t = 5000

Per1D_numerik = [0.0000000000000000
0.0615791152912970
0.1229152059473570
0.1837662064401560
0.2438919656709330
0.3030551947368550
0.3610224034018770
0.4175648215761000
0.4724593021667610
0.5254892017378690
0.5764452355029160
0.6251263032762330
0.6713402831235830
0.7149047895796720
0.7556478934402410
0.7934088002881240
0.8280384850752990
0.8594002802566890
0.8873704151544890
0.9118385044246280
0.9327079836971700
0.9498964906717900
0.9633361901641380
0.9729740418203220
0.9787720094429400
0.9807072111026920
0.9787720094427600
0.9729740418199780
0.9633361901637150
0.9498964906713340
0.9327079836967010
0.9118385044241720
0.8873704151540730
0.8594002802563460
0.8280384850750780
0.7934088002880230
0.7556478934402330
0.7149047895797260
0.6713402831236710
0.6251263032763290
0.5764452355030050
0.5254892017379160
0.4724593021667530
0.4175648215760600
0.3610224034018210
0.3030551947367990
0.2438919656709030
0.1837662064401370
0.1229152059473450
0.0615791152912920
0.0000000000000000];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik perbandingan antara analitik dan numerik 1 dimensi
% menampilkan galat_relatif = |nilai_analitik - nilai_numerik|./nilai_analitik

C1 = abs(Alum1D_analitik-Alum1D_numerik);
C2 = abs(Per1D_analitik-Per1D_numerik);
D1 = abs(C1./Alum1D_analitik);              % galat Aluminium 1 dimensi
D2 = abs(C1./Per1D_analitik);               % galat Aluminium 1 dimensi
x = [1:51]';                                % Sumbu-x
disp 'Selisih dan Galat Relatif Nilai Difusi Analitik dan Numerik'
disp '         1 Dimensi Bahan Aluminium dan Perak'
disp '          T(x,t); x = 1 s.d 51 dan t = 4500'
disp '===================================================================='
fprintf('             Selisih      Selisih     Galat Relatif    Galat Relatif\n')
fprintf('T(x,t)      Aluminium      Perak        Aluminium         Perak\n')
disp '--------------------------------------------------------------------'
fprintf('T(%g,4500)    %6.2d      %6.2d      %6.2d        %6.2d \n',[x,C1,C2,D1,D2]');
disp '===================================================================='

figure(1)
axis tight
plot(x,Alum1D_analitik,'*r',x,Alum1D_numerik,'ob')
legend('analitik','numerik')
set(legend,'FontAngle','italic')
title 'Perbandingan Analitik dan Numerik 1 Dimensi pada Bahan Aluminium t 5000'
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(2)
axis tight
plot(x,Per1D_analitik,'*r',x,Per1D_numerik,'ob')
legend2 = legend('analitik','numerik');
set(legend2,'FontAngle','italic')
title 'Perbandingan Analitik dan Numerik 1 Dimensi pada Bahan Perak t 5000'
xlabel 'Sumbu-x'
```

```
ylabel 'Temperatur'

figure(3)
axis tight
plot(x,C1,'*r',x,C2,'+g')
title 'Perbandingan Selisih Numerik 1 Dimensi Bahan Aluminium dan Perak t 5000 '
legend3 = legend('selisih bahan Aluminium numerik','selisih bahan Perak numerik');
set(legend3,'FontAngle','italic')
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(4)
axis tight
plot(x,Alum1D_numerik,'Pg',x,Per1D_numerik,'-.g',x,Alum1D_analitik,'-r',...
    x,Per1D_analitik,'*r')
title 'Perbandingan Analitik dan Numerik 1 Dimensi Bahan Aluminium dan Perak t 5000'
legend4 = legend('bahan Aluminium numerik','bahan Perak numerik',...
    'bahan Aluminium analitik','bahan Perak analitik');
set(legend4,'FontAngle','italic')
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(5)
axis tight
plot(x,D1,'Hb')
legend('galat relatif Aluminium')
set(legend,'FontAngle','italic')
title 'Galat Relatif Bahan Aluminium 1 Dimensi t 5000'
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(6)
axis tight
plot(x,D2,'Hb')
legend('galat relatif Perak')
set(legend,'FontAngle','italic')
title 'Galat Relatif Bahan Perak 1 Dimensi t 5000'
xlabel 'Sumbu-x'
ylabel 'Temperatur'

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Perbandingan difusi panas hasil analitik dan numerik bahan Aluminium dan
% bahan Perak 2 dimensi.
% Difusi panas pada T(x,y,t) dengan x = 1 sampai dengan 51, y = 1 sampai
% dengan 51 dan t = 1 sampai dengan 4500.
% Data yang dtampilkan dibawah ini adalah data pada t = 2000, nilai x dan y
% berubah dari 1 sampai dengan 51 sedangkan t adalah tetap.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% hasil nilai analitik bahan Aluminium 1 dimensi pada x,y = 1 sampai dengan 51
% dan t = 4500

Alum2D_analitik = [0.0000000000000000
0.0038826859475750
0.0154695115135030
0.0345777455369750
0.0609060397527350
0.0940391812332390
0.1334546405445620
0.1785308123477100
0.2285568184861460
0.2827437189589800
0.3402369539760710
0.4001298208764050
0.4614777733706990
0.5233133176006280
0.5846612700949220
0.6445541369952560
0.7020473720123470
0.7562342724851820
0.8062602786236180
0.8513364504267650
0.8907519097380880
0.9238850512185930
0.9502133454343530
0.9693215794578240
0.9809084050237520
0.9847910909713270
0.9809084050237520
0.9693215794578250
0.9502133454343530
0.9238850512185930
0.8907519097380880
0.8513364504267650
0.8062602786236180
0.7562342724851810
0.7020473720123470
0.6445541369952560
0.5846612700949220
0.5233133176006280
0.4614777733706990
0.4001298208764050
0.3402369539760710
0.2827437189589810
0.2827437189589810
0.1785308123477100
0.1334546405445620
0.0940391812332390
0.0609060397527350
0.0345777455369750
0.0154695115135030
0.0038826859475750
0.0000000000000000];

% hasil nilai numerik bahan Aluminium 1 dimensi pada x,y = 1 sampai dengan 51
% dan t = 4500

Alum2D_numerik = [0.000000000000000
0.005277370564018
0.021031407432804
0.047028948910853
0.082884923705505
```

```
0.128067609544072
0.181905917823963
0.243598626791117
0.312225463525100
0.386759912834761
0.466083609148203
0.549002145781180
0.634262114812617
0.720569170467193
0.806606889741398
0.891056186400999
0.972615018857199
1.050018119260580
1.122056460919540
1.187596174338820
1.245596619255370
1.295127321459560
1.335383489314710
1.365699836037540
1.385562450198180
1.394618478651010
1.392683413207220
1.379745804658150
1.355969264964480
1.321691660100470
1.277421441595380
1.223831113514430
1.161747882602770
1.092141591594360
1.016110088179920
0.934862233679994
0.849698804878874
0.761991588530506
0.673161009557409
0.584652669795060
0.497913203247197
0.414365875301158
0.414365875301158
0.262279185276224
0.196255150161012
0.138410364970079
0.089707089739028
0.050956874965772
0.022806286907081
0.005725502802846
0.000000000000000];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% hasil nilai analitik bahan Perak 1 dimensi pada x,y = 1 sampai dengan 51
% dan t = 4500

Per2D_analitik = [0.0000000000000000
0.0038358447301930
0.0152828853579520
0.0341605952144490
0.0601712615382490
0.0929046805834050
0.1318446267775810
0.1763769939076970
0.2257994799417640
0.2793326627514640
0.3361322920647130
0.3953026037967890
0.4559104467850450
0.5169999991401870
0.5776078421284430
0.6367781538605180
0.6935777831737680
0.7471109659834680
0.7965334520175350
0.8410658191476510
0.8800057653418260
0.9127391843869830
0.9387498507107830
0.9576275605672790
0.9690746011950390
0.9729104459252320
0.9690746011950390
0.9576275605672800
0.9387498507107830
0.9127391843869830
0.8800057653418260
0.8410658191476510
0.7965334520175350
0.7471109659834670
0.6935777831737680
0.6367781538605180
0.5776078421284430
0.5169999991401860
0.4559104467850460
0.3953026037967890
0.3361322920647140
0.2793326627514640
0.2793326627514640
0.1763769939076970
0.1318446267775810
0.0929046805834060
0.0601712615382490
0.0341605952144490
0.0152828853579520
0.0038358447301930
0.0000000000000000];

% hasil nilai numerik bahan Perak 2 dimensi pada x,y = 1 sampai dengan 51
% dan t = 4500

Per2D_numerik = [0.000000000000000
0.003356913134605
0.013379964781259
0.029926676594040
0.052761530599093
0.081558874638559
0.115906962700983
0.155313102003946
0.199209869508003
0.246962350589824
0.297876341820168
0.351207448169688
```

```
0.406170992555596
0.461952642564615
0.517719645629700
0.572632550153900
0.625857276381780
0.676577387591738
0.724006399844490
0.767399957535037
0.806067692842956
0.839384580353563
0.866801594117171
0.887855473686081
0.902177408634290
0.909500458073553
0.909665532997446
0.902625785076039
0.888449265832392
0.867319744870266
0.839535604758876
0.805506762934508
0.765749607018861
0.720879968601993
0.671604200978911
0.618708467628143
0.563046389344495
0.505525237782748
0.447090900592859
0.388711877187925
0.331362593380786
0.276006346630252
0.276006346630252
0.174968236920864
0.131005295105011
0.092441882308631
0.059940223233863
0.034059954783507
0.015247660803702
0.003828484199904
0.000000000000000];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik perbandingan antara analitik dan numerik 2 dimensi
% menampilkan galat_relatif = |nilai_analitik - nilai_numerik|./nilai_analitik

C1 = abs(Alum2D_analitik-Alum2D_numerik);
C2 = abs(Per2D_analitik-Per2D_numerik);
D1 = abs(C1./Alum2D_analitik);              % galat Aluminium 2 dimensi
D2 = abs(C1./Per2D_analitik);               % galat Perak 2 dimensi
x = [1:51]'; y = x;                         % Sumbu-x,y
disp 'Selisih dan Galat Relatif Nilai Difusi Analitik dan Numerik'
disp '         2 Dimensi Bahan Aluminium dan Perak'
disp '        T(x,y,t); x,y = 1 s.d 51 dan t = 2000'
disp '===================================================================='
fprintf('               Selisih      Selisih    Galat Relatif    Galat Relatif\n')
fprintf('T(x,y,t)      Aluminium      Perak       Aluminium         Perak\n')
disp '--------------------------------------------------------------------'
fprintf('T(%d,%d,2000)    %6.2d      %6.2d      %6.2d        %6.2d \n',[x,x,C1,C2,D1,D2]');
disp '===================================================================='

figure(1)
axis tight
plot(x,Alum2D_analitik,'*r',x,Alum2D_numerik,'ob')
legend('analitik','numerik')
set(legend,'FontAngle','italic')
title 'Perbandingan Analitik dan Numerik 2 Dimensi pada Bahan Aluminium t 2000'
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(2)
axis tight
plot(x,Per2D_analitik,'*r',x,Per2D_numerik,'ob')
legend2 = legend('analitik','numerik');
set(legend2,'FontAngle','italic')
title 'Perbandingan Analitik dan Numerik 2 Dimensi pada Bahan Perak t 2000'
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(3)
axis tight
plot(x,C1,'*r',x,C2,'+g')
title 'Perbandingan Selisih Numerik 2 Dimensi Bahan Aluminium dan Perak t 2000 '
legend3 = legend('selisih bahan Aluminium numerik','selisih bahan Perak numerik');
set(legend3,'FontAngle','italic')
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(4)
axis tight
plot(x,Alum2D_numerik,'Pg',x,Per2D_numerik,'-.g',x,Alum2D_analitik,'-r',...
    x,Per2D_analitik,'*r')
title 'Perbandingan Analitik dan Numerik 2 Dimensi Bahan Aluminium dan Perak t 2000'
legend4 = legend('bahan Aluminium numerik','bahan Perak numerik',...
    'bahan Aluminium analitik','bahan Perak analitik');
set(legend4,'FontAngle','italic')
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(5)
axis tight
plot(x,D1,'Hb')
legend('galat relatif Aluminium')
set(legend,'FontAngle','italic')
title 'Galat Relatif Bahan Aluminium 2 Dimensi t 2000'
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(6)
axis tight
plot(x,D2,'Hb')
legend('galat relatif Perak')
set(legend,'FontAngle','italic')
title 'Galat Relatif Bahan Perak 2 Dimensi t 2000'
xlabel 'Sumbu-x'
ylabel 'Temperatur'

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Perbandingan difusi panas hasil analitik dan numerik bahan Aluminium dan
% bahan Perak 3 dimensi.
```

```
% Difusi panas pada T(x,y,z,t) dengan x = 1 sampai dengan 25, y = 1 sampai
% dengan 25  dan t = 1 sampai dengan 1500.
% Data yang dtampilkan dibawah ini adalah data pada t = 500, nilai x dan y
% berubah dari 1 sampai dengan 51 sedangkan t adalah tetap.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% hasil nilai analitik bahan Aluminium 3 dimensi pada x = 1 sampai dengan
% 25 dan y,z = 20 sedangkan t = 100

Alum3D_analitik = [0.0000000000000000
0.0000000711232985
0.0000001411249401
0.0000002089009570
0.0000002733824811
0.0000003335526002
0.0000003884623955
0.0000004372459067
0.0000004791337889
0.0000005134654449
0.0000005396994441
0.0000005574220608
0.0000005663537985
0.0000005663537985
0.0000005574220608
0.0000005396994441
0.0000005134654449
0.0000004791337889
0.0000004372459067
0.0000003884623955
0.0000003335526002
0.0000002733824811
0.0000002089009570
0.0000001411249401
0.0000000711232985
0.0000000000000000];

% hasil nilai numerik bahan Aluminium 3 dimensi pada x = 1 sampai dengan
% 25 dan y,z = 20 sedangkan t = 500

Alum3D_numerik = [0.0000000000000000
0.0000002063070862
0.0000004093486682
0.0000006059116952
0.0000007928871069
0.0000009673195626
0.0000011264545175
0.0000012677818655
0.0000013890754532
0.0000014884278588
0.0000015642799323
0.0000016154446914
0.0000016411252706
0.0000016409267150
0.0000016148615004
0.0000015633487497
0.0000014872071939
0.0000013876420044
0.0000012662257014
0.0000011248734174
0.0000009658128730
0.0000007915494987
0.0000006048272158
0.0000004085854597
0.0000002059131041
0.0000000000000000];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% hasil nilai analitik bahan Perak 3 dimensi pada x = 1 sampai dengan
% 25 dan y,z = 20 sedangkan t = 500

Per3D_analitik = [0.0000000000000000
0.0000000000008272
0.0000000000016415
0.0000000000024298
0.0000000000031798
0.0000000000038796
0.0000000000045183
0.0000000000050857
0.0000000000055729
0.0000000000059722
0.0000000000062774
0.0000000000064835
0.0000000000065874
0.0000000000065874
0.0000000000064835
0.0000000000062774
0.0000000000059722
0.0000000000055729
0.0000000000050857
0.0000000000045183
0.0000000000038796
0.0000000000031798
0.0000000000024298
0.0000000000016415
0.0000000000008272
0.0000000000000000];

% hasil nilai numerik bahan Perak 3 dimensi pada x = 1 sampai dengan
% 25 dan y,z = 20 sedangkan t = 500

Per3D_numerik = [0.00000000000000000000
0.00000000000081868384
0.00000000000162443148
0.00000000000240451229
0.00000000000314660432
0.00000000000383898889
0.00000000000447073794
0.00000000000503188496
0.00000000000551358461
0.00000000000590824908
0.00000000000620967001
0.00000000000641311190
```

```
0.00000000000651538897
0.00000000000651491013
0.00000000000641170644
0.00000000000620742529
0.00000000000590530706
0.00000000000551012928
0.00000000000502813424
0.00000000000446692676
0.00000000000383535738
0.00000000000314338010
0.00000000000240189840
0.00000000000162259182
0.00000000000081773424
0.00000000000000000000];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik perbandingan antara analitik dan numerik 3 dimensi
% menampilkan galat_relatif = |nilai_analitik - nilai_numerik|./nilai_analitik

C1 = abs(Alum3D_analitik-Alum3D_numerik);
C2 = abs(Per3D_analitik-Per3D_numerik);
D1 = abs(C1./Alum3D_analitik);              % galat Aluminium 3 dimensi
D2 = abs(C1./Per3D_analitik);               % galat Perak 3 dimensi
x = [1:26]'; y = x; z = y;                  % Sumbu-x,y,z
disp 'Selisih dan Galat Relatif Nilai Difusi Analitik dan Numerik'
disp '         3 Dimensi Bahan Aluminium dan Perak'
disp '     T(x,y,z,t); x = 1 s.d 51; y,z = 20 dan t = 500'
disp '===================================================================='
fprintf('                 Selisih     Selisih    Galat Relatif   Galat Relatif\n')
fprintf('T(x,y,z,t)      Aluminium     Perak       Aluminium        Perak\n')
disp '--------------------------------------------------------------------'
fprintf('T(%g,20,20,500)   %6.2d    %6.2d     %6.2d       %6.2d \n',[x,C1,C2,D1,D2]');
disp '===================================================================='

figure(1)
axis tight
plot(x,Alum3D_analitik,'*r',x,Alum3D_numerik,'ob')
legend('analitik','numerik')
set(legend,'FontAngle','italic')
title 'Perbandingan Analitik dan Numerik 3 Dimensi pada Bahan Aluminium t 500'
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(2)
axis tight
plot(x,Per3D_analitik,'*r',x,Per3D_numerik,'ob')
legend2 = legend('analitik','numerik');
set(legend2,'FontAngle','italic')
title 'Perbandingan Analitik dan Numerik 3 Dimensi pada Bahan Perak t 500'
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(3)
axis tight
plot(x,C1,'*r',x,C2,'+g')
title 'Perbandingan Selisih Numerik 3 Dimensi Bahan Aluminium dan Perak t 500 '
legend3 = legend('selisih bahan Aluminium numerik','selisih bahan Perak numerik');
set(legend3,'FontAngle','italic')
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(4)
axis tight
plot(x,Alum3D_numerik,'Pg',x,Per3D_numerik,'-.g',x,Alum3D_analitik,'Or',...
    x,Per3D_analitik,'*r')
title 'Perbandingan Analitik dan Numerik 3 Dimensi Bahan Aluminium dan Perak t 500'
legend4 = legend('bahan Aluminium numerik','bahan Perak numerik',...
    'bahan Aluminium analitik','bahan Perak analitik');
set(legend4,'FontAngle','italic')
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(5)
axis tight
plot(x,D1,'Hb')
legend('galat relatif Aluminium')
set(legend,'FontAngle','italic')
title 'Galat Relatif Bahan Aluminium 3 Dimensi t 500'
xlabel 'Sumbu-x'
ylabel 'Temperatur'

figure(6)
axis tight
plot(x,D2,'Hb')
legend('galat relatif Perak')
set(legend,'FontAngle','italic')
title 'Galat Relatif Bahan Perak 3 Dimensi t 500'
xlabel 'Sumbu-x'
ylabel 'Temperatur'

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Perbandingan difusi panas hasil numerik bahan multilayer.
% Data yang dtampilkan di bawah ini adalah data pada t = 2000, nilai x
% berubah dari 1 sampai dengan 40 sedangkan t adalah tetap.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clc;
clf;
clear all;
close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% data bahan Aluminium-Perak-Aluminium x = 1 sampai dengan 41 dan t = 2000

Al_Ag_Al = [0
0.044672729211015
0.088989482651025
0.132596364788051
0.175143657271498
0.216287947928909
0.255694304506961
0.293038501962991
0.328009307138533
```

```
0.360310818755159
0.389664854083817
0.415813366611152
0.438520871855328
0.457576851493551
0.472798099495528
0.484030968357161
0.491153469130055
0.494077176047028
0.492748885403606
0.487151979152954
0.477307446503643
0.463274521673632
0.445150902740951
0.423072525024322
0.397212872306018
0.367781820065796
0.337831828007437
0.336596237148006
0.332547472836773
0.325707712562814
0.316124593970414
0.303870800009481
0.289043379463011
0.271762820574552
0.252171897950271
0.230434314330443
0.204511175988131
0.155077347710092
0.104196315521549
0.052342538870396
0];

% data bahan Perak-Aluminium-Perak x = 1 sampai dengan 41 dan t = 2000
Ag_Al_Ag = [0
0.049674349009200
0.099179763734462
0.148349282166688
0.197019842671036
0.245034124810342
0.292242261921126
0.338503387612752
0.383686982451956
0.427673992050019
0.470357693479040
0.511644293273737
0.551453247070128
0.589717298015563
0.626382238262096
0.661406404921371
0.694759928603106
0.726423758872883
0.756388496452056
0.784653066568191
0.811223271403694
0.836110261976668
0.859328970959679
0.880896547885828
0.900830836944442
0.919148935215981
0.937433078115233
0.867809808927131
0.796622383666008
0.724037924962936
0.650217184100112
0.575314337367969
0.499477016776481
0.422846557403301
0.345558439728627
0.267742902496216
0.196230031511194
0.147401417489638
0.098376012404882
0.049220406300332
0];


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% menampilkan grafik

x = [0:40];
plot(x,Al_Ag_Al,'*r',x,Ag_Al_Ag,'ob')
axis tight
legend = legend('Al-Ag-Al','Ag-Al-Ag');
set(legend,'FontAngle','italic')
title 'Perbandingan bahan Multilayer Al-Ag-Al dan Ag-Al-Ag t 2000'
xlabel 'Sumbu-X'
ylabel 'Temeperatur'
```