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Properties behind effective Transformer Oil Cooling

Hendrik Cosemans, General Manager Nynas Dubai

As a Belgian national, where 3 official languages are part of the national structure, Hendrik is adding English and Spanish to his language portfolio. And very basics of Arabic, but he would like to improve these skills.

Trained as a Business Engineer he has travelled the world, both in his studies and work experience. Barcelona, Belfast and Dubai have little secrets for him. He moved from Linde Gas to Nynas in 2007.

Being active in the field of sales or purchasing, the commercial surroundings are where he thrives best. The international business scene was swapped for Dubai's iconic landscape since 2011, together with his family. As General Manager of Nynas Dubai, a further growth of the 15 countries under his responsibility has been achieved. Transformer oils remain the main focus of the Naphthenic oils that are being produced by Nynas, next to process-oils, oil for lubes & greases and tyre-oils.

Setting up good cooperation and local partnerships, lobbying for quality prescriptions and passing the knowledge via conferences and seminars, whilst travelling actively to meet the customers, contractors and utilities are the main activities, next to ensuring that the Dubai office keeps delivering its excellent performance in order handling and customer satisfaction.

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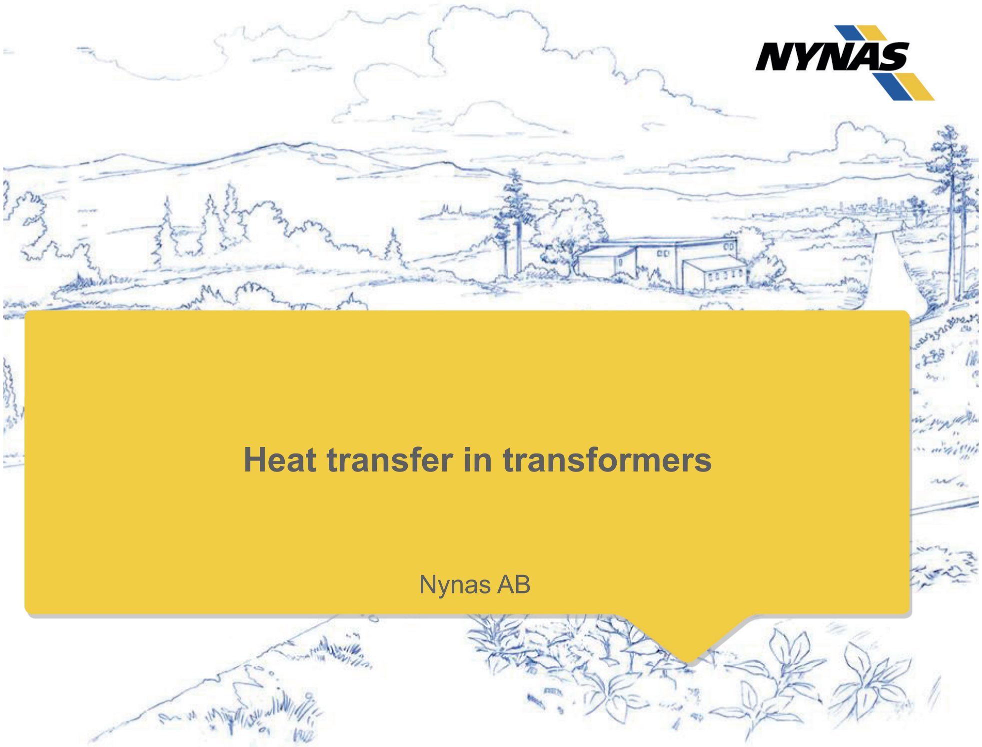

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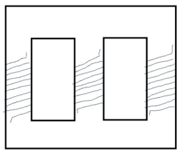
Cooling properties of insulating liquid

Properties behind effective Transformer Oil Cooling

Cooling

- Heat generation in transformers
- Viscosity
- Heat transfer coefficient

Heat generation in transformers



There are two main types of losses of power in transformers: "No load" losses and Load losses

- **"No load" losses**: Independent of load of transformer
  - Comes from magnetic losses and hysteresis in the iron core
- **Load losses** = Copper electrical resistance loss + Stray losses
  - Copper electrical resistance loss: $Q_R \approx I{*}R^2$ = =Electric Current * Resistance^2
  - Stray losses: Leakage of electric flux and eddy losses to tank and other metal parts
  - Copper electrical resistance loss: $R(T)=R_0 + \alpha{*}T$
    - (Where T= Temperature, with constants R_0 and α)

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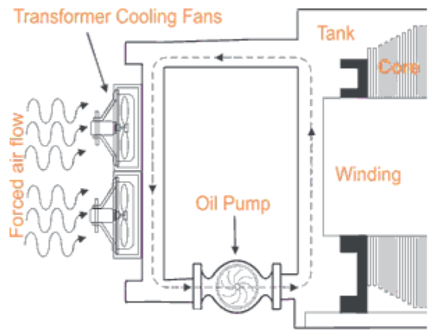
Example of heat generation in a transformer

- TRAFO: 630 kVA (15kV/0.42 kV), with 3 MT of TRO
- Losses (Q) in TRAFO
  - Q_{Core}= 600 W and Q_{Load}= 4600 W
    - Reference: EFACEC 2012
- To keep temperature steady in the transformer the cooler needs to remove 5200 W from the oil!
- If no cooler is installed, the oil temperature will rise 3°C in 1 hour!
- Cellulose degrades faster at higher temperature!



Oil Forced Air Forced or OFAF Cooling of Transformer

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Convective and conductive heat transfer

Convective heat transfer is the cooling from the cold wind (flowing air), and is the chilling effect on your bare skin and through your clothes.

Conductive heat transfer is the cooling through the clothes (in stagnant air) and no wind all.

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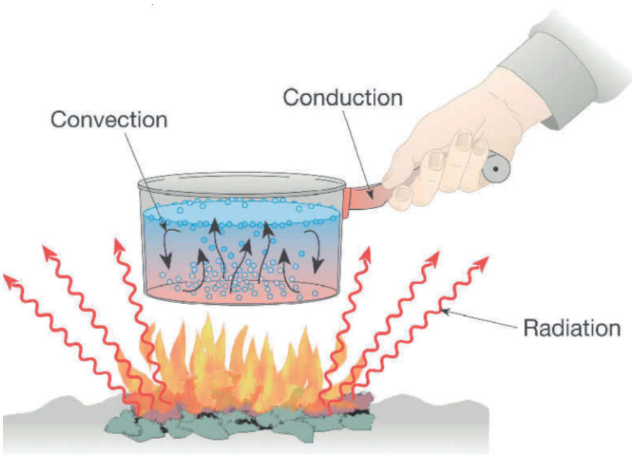
Heat transfer – overview



Specific heat capacity, c_p

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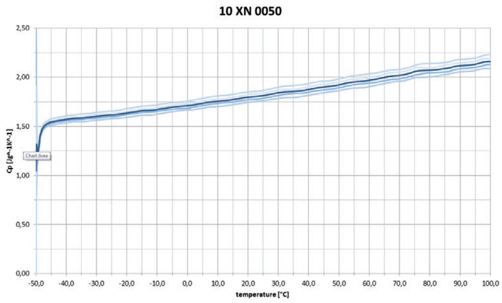
- Specifies the amount of heat required to change the temperature of an object or solid/liquid/gas by a given amount.
  - Example: In order to increase the temperature 1 K of 1 kg naphthenic transformer oil at 40°C : 1875 J/(kg*K). This means that 1875 J is needed to be transfered to 1 kg of oil to increase the temperature to 41°C.
  - The specific heat capacity is changing over increasing temperatures as shown below



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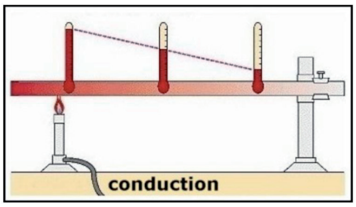
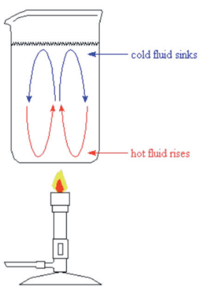
Thermal conductivity

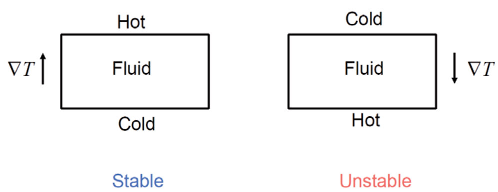
- **Thermal conductivity, k**
  - Specifies how a material conduct heat flux from a point to another. The heat conductivity is measured in stagnant fluid at a certain temperature.
    - In order to transport heat flux through a layer of naphthenic transformer oil at 40°C; k=0,310 W/(m*K)
    - Thermal conductivity is important part of total heat transfer in the boundary layer at laminar flow (high viscosity and/or low flow velocity)



Density and its´role in heat transfer

- Density ρ ; Describes how many kilograms 1 m^3 of fluid weight at a certain temperature.
  - Density is changing over temperature due to volume expansion at higher temperature
  - Natural convection is heat transfer where the density gradient drives the circulation: warm fluid rises (stable) and cold fluid sinks (unstable)





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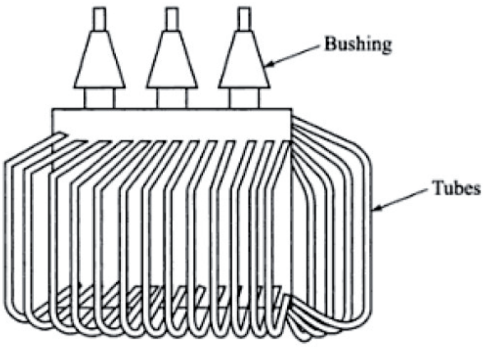
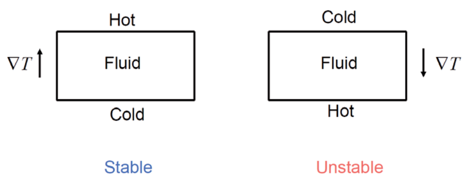
ONAN cooling of transformer

- The warmer oil rises to the top and cools down and flows to the bottom in the tubes mounted in the mantle. For transformers below 25kVA is ONAN common.





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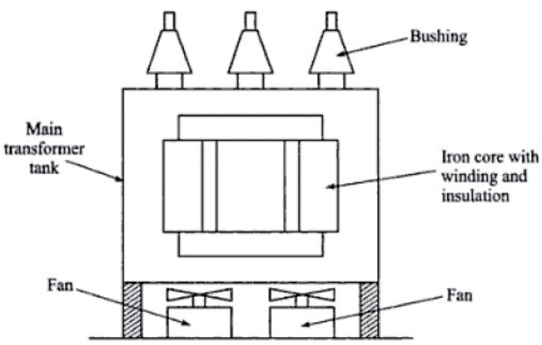
ONAF cooling of transformer

- The oil is cooled by a fan (forced air flow) in the heat transfer zone



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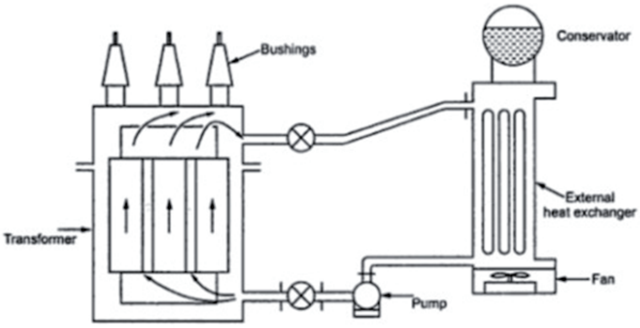
OFAF cooling of transformer

- The oil is (forced or) pumped to the heat transfer zone where the air is forced by a fan. OF cooling is the common choice for transformer above 60MVA.
- OEMs recommends a maximum flow velocity of 1 m/s for the insulation oil .
  - In practice the velocity is around 0.5 m/s and up to 1 m/s.
  - Above 1 m/s there is risk for static electricity charges build up, or ECT



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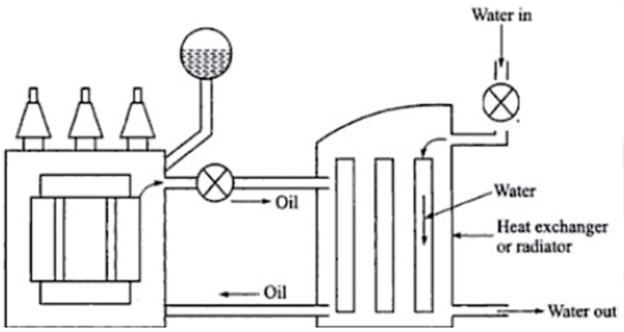
OFWF

- Water cooling is more effiecient than air cooling. Corrosion and leakage might be an issue when used in transformers. Cp and k is much higher for water than for air.



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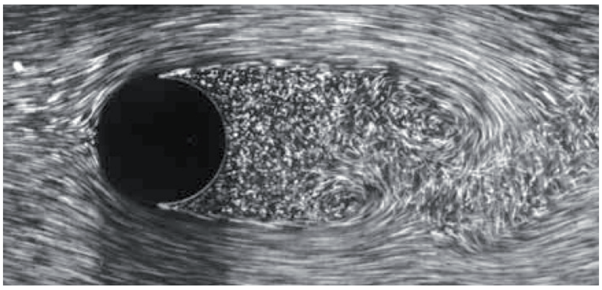
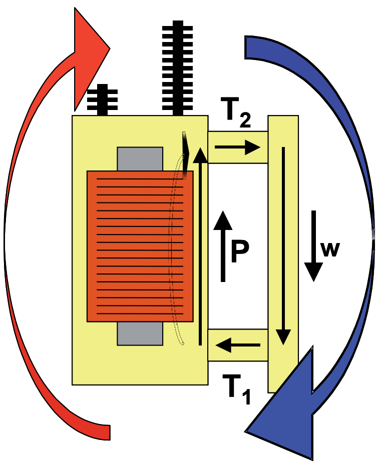
Properties behind effective Transformer Oil Cooling

Viscosity

- Lowest possible viscosity is the best way to obtain rapid and efficient cooling in a transformer



Virtual Oil Wheel



Calculation of the natural oil circulation speed on basis of the Laws of Bernoulli, Newton, Reynolds and Prandtl.

$$w = f \cdot \frac{\Delta p}{\nu}$$

w = Oil flow speed
f = Calculation factor
n = Kin. viscosity at operation temperature
p = force from buoyancy

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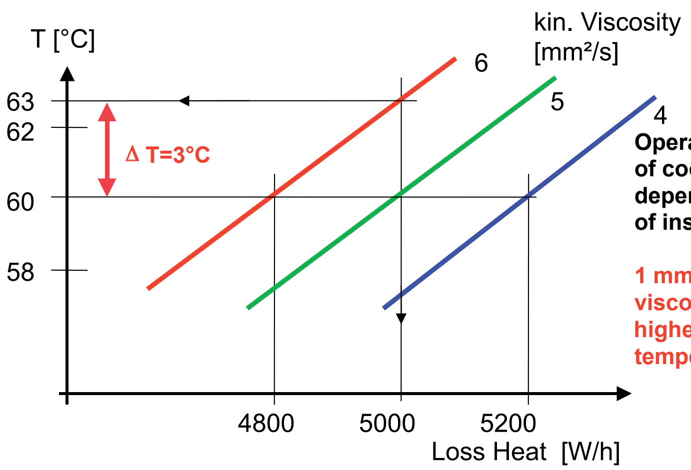
Influence of Viscosity to Heat Dissipation



Operation temperature of cooling system depends on viscosity of insulating oil

1 mm²/s higher working-viscosity leads to 3°C higher operation-temperature

Viscosity index

- Oil with lower viscosity index have better cooling properties
  - Naphthenic oil have lower viscosity index

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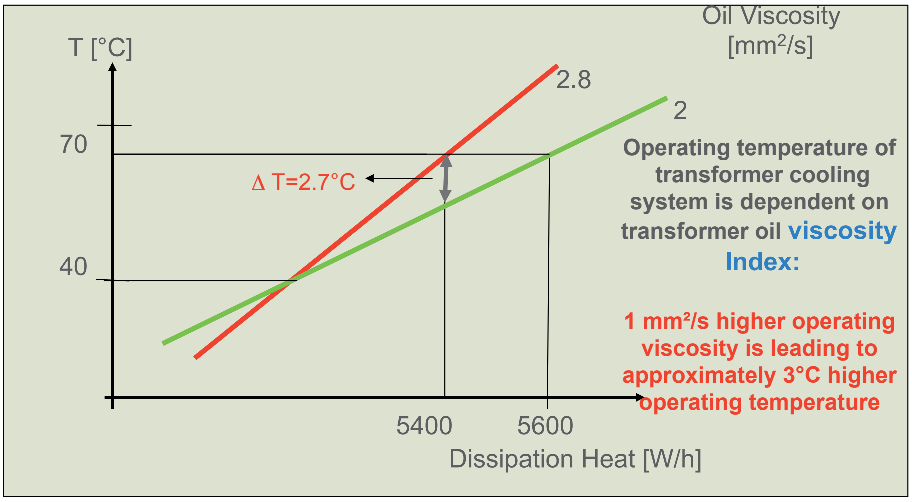
Transformer Operating Temperature for two oils with the same viscosity at 40 C



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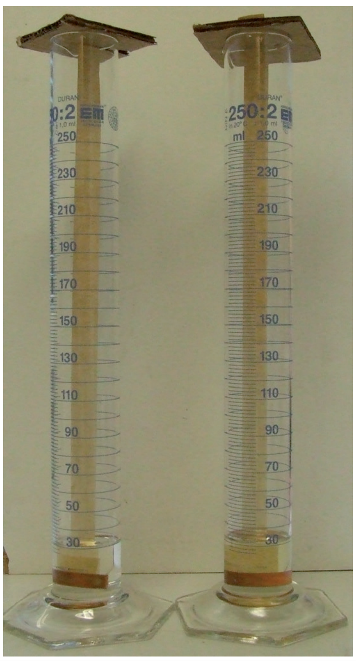
Hanging Paper Wetting

- Level of oil wetting checked over 72 h
- Two oils compared
  - Paraffinic
    Visc. 40 ˚C 10.6 cSt
    Visc. 20 ˚C 22.5 cSt
  - Naphthenic
    Visc. 40 ˚C 9.1
    Visc. 20 ˚C 19.5



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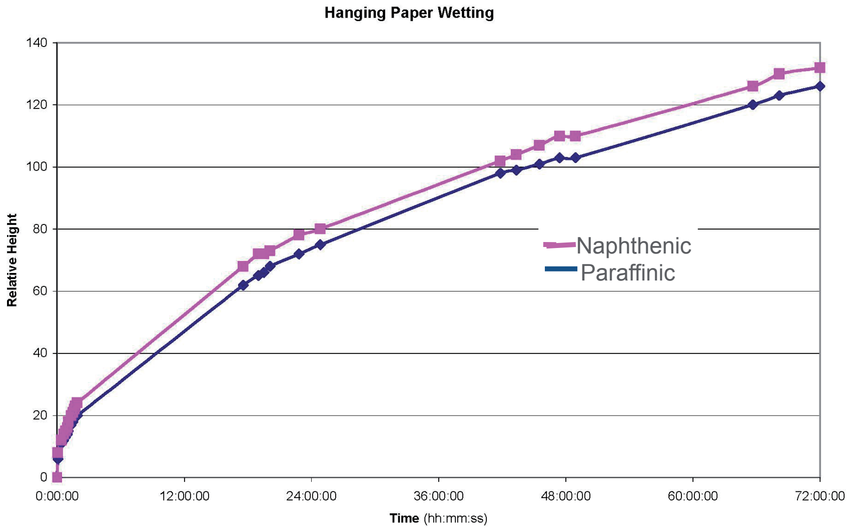
Results over time



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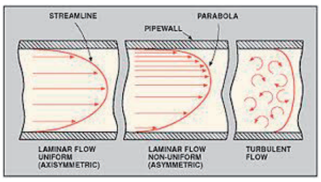
Reynolds number



- Reynolds number: Re= $u*D/\nu$
  - u = Flow velocity of the oil in $[m/s]$
  - D= Characteristic lenght, which is for a pipe the diameter in [m]
  - ν = Kinematic viscosity in $[m2/s]$
- In pipes: At Re 2300 the flow will change from laminar to turbulent and over 5000 fully turbulent is developed
- $Inertial\ forces/Viscous\ forces$
  - When the inertial forces dominates over the viscous forces, small turbulent eddys increases mixing between warmer oil and cooler oil during the flow and enhances heat and mass transfer

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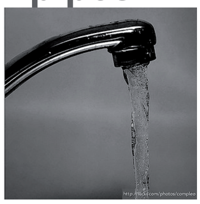
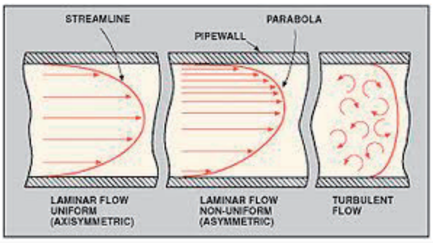
Flowing fluid and heat transfer in pipes

- At higher flow velocity the fluid will develop turbulence and this will be beneficial for the heat transfer.
- A lower viscosity increases heat transfer and turbulence

Turbulent flow



Laminar flow



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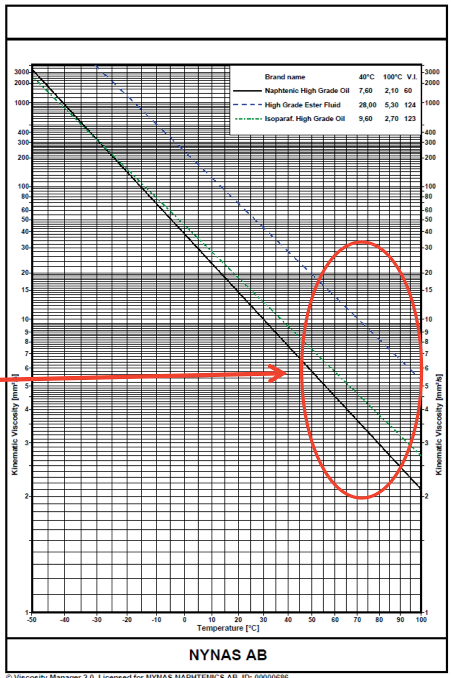
Viscosity and VI

This temperature zone is interesting for investigating cooling properties of oils



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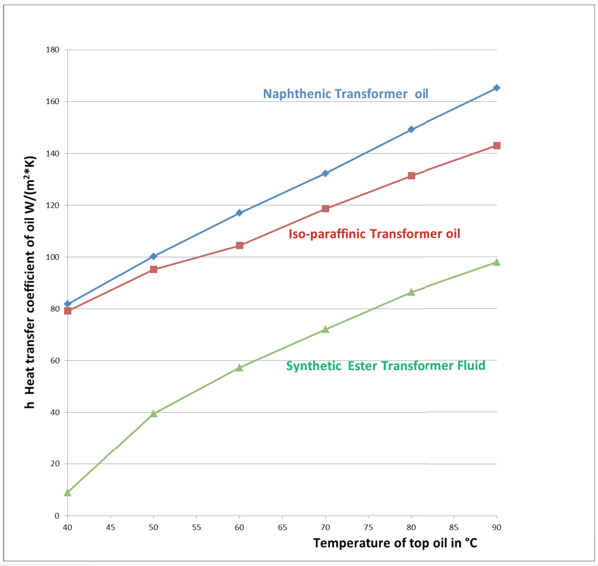
Heat transfer coefficient of three different types of transformer fluids



Cooler data:
Pipe Ø: 10 cm
Velocity: 0.5 m/s

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Conclusions

- The viscosity is the dominant physical property for the heat transfer coefficient
  - A lower viscosity increases heat transfer
  - Oil with lower viscosity have much better cooling properties
  - Oil with lower viscoisty can impregnate insulating paper much faster
- Forced convection is the best way to increase cooling rate on a surface
- A better cooling capacity in a transformer fluid lowers the overall temperatures in the unit and potentially extends cellose life time

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Thank you! Any questions?