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BALIKESIR ELECTROMECHANICAL INDUSTRIAL PLANTS CO.

DEVELOPMENT OF A TEST ROOM IN ORDER TO EXAMINE TRANSFORMER COOLING SYSTEMS

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Introduction

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- Thermal performance of power transformers has a significant effect on service life.
- Flow characteristics within the active part and cooling equipment as well as dimensions effects the heat transfer rate.
- To better understand oil flow in the windings based on design parameters (spacer width, disc width, cooling duct width etc.) CFD simulation tools can be used.
- With coupled heat and flow solver, heat transfer parameters between cooling medium and heat generating sources can be determined.
- Some software couples electromagnetic and CFD simulations in steady state and transient conditions
- Increased capabilities of simulation tools can be used to determine thermal and hydrodynamic properties of power transformers and reactors

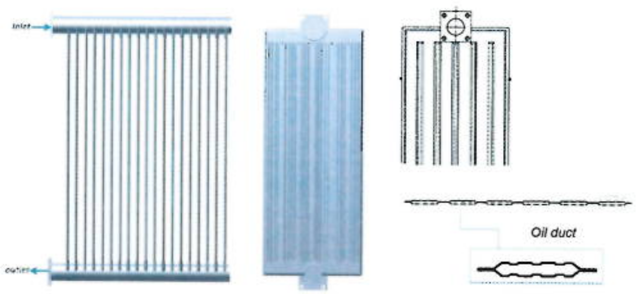
Difficulties with CFD Simulations

- Power transformers' dimensions are becoming larger as the power rating increases
- Number of mesh and nodes increase as the dimensions become larger
- Simplifications are necessary to run the simulations
- Symmetries with respect to some axis do not bring sufficient simplifications to the model

Radiator CFD Analysis

Radiator Model/ONAN

- Radiator cross-sections are very thin
- To capture the true behavior of the flow at oil-duct boundaries, inflation needs to be implemented
- This generates very high number of mesh even for single radiator section



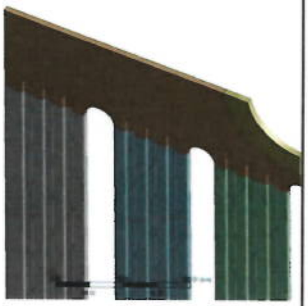
BEST Radiator CFD Analysis

Radiator model/ONAN

- Single section radiator can be modeled with quarter model utilizing the symmetry in terms of both the dimensions and the flow
- Even in this case, for large power transformers, **2,143,041** mesh elements are needed without fans and pumps.
- Great simplifications can be obtained by modeling radiators as porous model

Flow volume model

Flow volume mesh

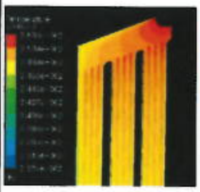


Quarter flow volume model

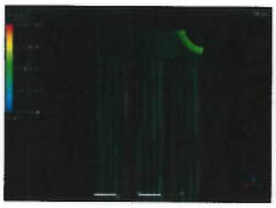
BEST Radiator CFD Analysis

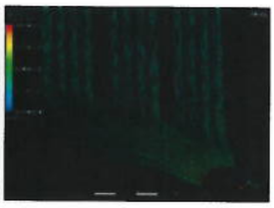
CASE (Natural ester transformer oil)

$T_{inlet} = 353\ K$
$v_{inlet} = 0.05\ m/s$



Temperature distribution at inlet



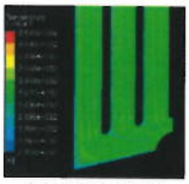


Results:

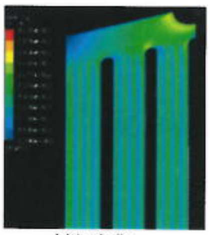
$T_{outlet} = 345.7\ K$

$\dot{q} = 284.87 \frac{W}{m^2}$

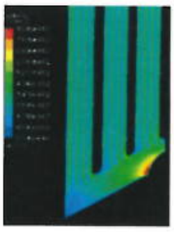
$\Delta P = 190.77\ Pa$



Temperature distribution at outlet



Inlet-velocity



Outlet-velocity

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Radiator CFD Analysis

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Porous Model

- Porous model needs Pressure Drop vs. Velocity graph of the radiator
- Simulations need to be run on actual, ¼ symmetric, model of the transformer
- Outlet temperature, Pressure Drop and Heat Flux can be obtained based on the given boundary conditions.

Velocity	Outlet Temperature	Pressure Drop	Heat Flux
m/s	*K*	*Pa*	*W/m2*
0.05	345.6837	190.7731	284.8672
0.04	344.1276	159.2608	280.0674
0.03	341.6559	127.4781	272.5842
0.02	337.0856	94.8802	258.6851

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Radiator CFD Analysis

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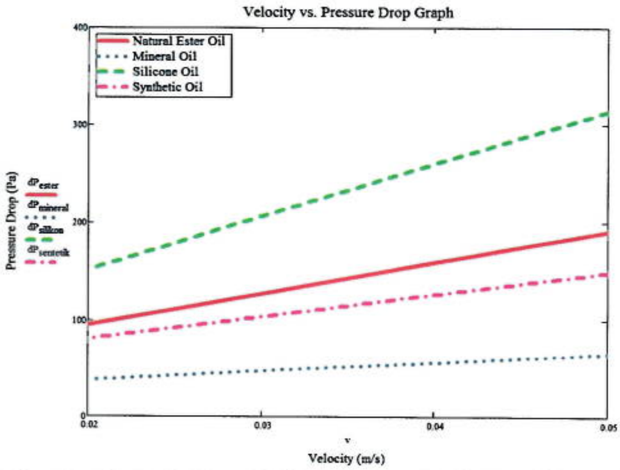
Porous Model – Velocity vs. Pressure Drop Graph

- Simulations can be carried out for different oil types
- Whole cooling unit can be modeled using porous zone to save from computation time

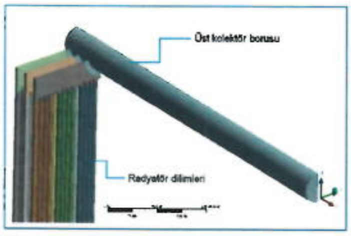


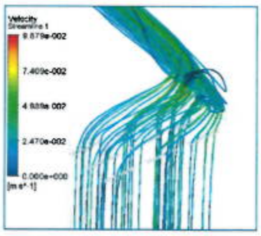
Radiator CFD Analysis

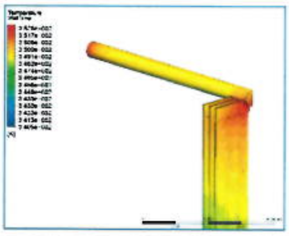
Porous Model – Validation with 3 Section Model

- Simulations are also checked with three sections and collector pipe to validate single section model

Oil Flow in Cooling Duct (Porous Model)	ΔP/L (Radiator)	Collector Oil Entry Velocity	Radiator Oil Entry Velocity	ΔP (Radiator)
(m/s)	(Pa)	(m/s)	(m/s)	(Pa)
0.0025	15.8004	0.00535	0.01	50.56128
0.005	30.2713	0.01069	0.02	96.86816
0.0074	41.6955	0.01604	0.03	133.4256
0.0099	53.6156	0.02139	0.04	171.56992
0.0124	64.8941	0.02673	0.05	207.66112
0.0149	76.1434	0.03208	0.06	243.65888
0.0173	86.9805	0.03743	0.07	278.3376



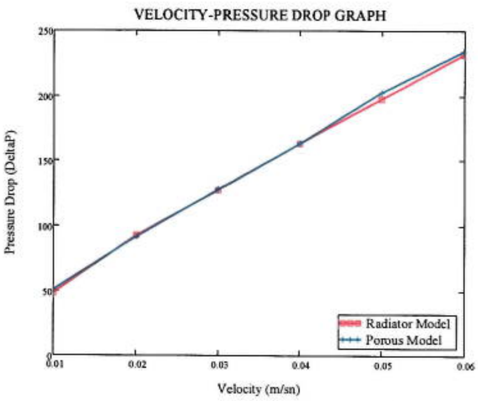




Radiator CFD Analysis

Comparision of Radiator Model and Porous Model

- Same simulations are also carried out with porous model.
- Viscous resistance coefficient for radiators are determined.
- Great simplifications for whole transformer CFD analysis can be performed.



Test Room

Why Test Room is Needed?

- All these efforts and simulations need to be validated.
- Convection coefficients on air side has to be determined for radiators with multiple number of sections.
- As the number of sections increase, heat dissipation characteristics of radiator decrease.
- Performance of different oil can be determined and compared.
- Different radiator oil-duct geometries, fan and pump performances can be tested.
- Test room can be used to determine thermal and hydrodynamic characteristics of windings with some modifications in future.
- Performance of cooling equipment at different temperatures can be tested.

Test Room

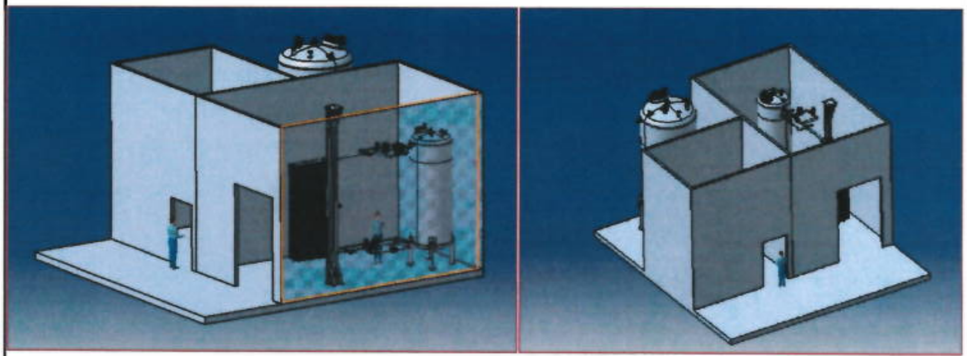
Test Room Capacity

- Test room is designed so that temperature range between **-20 ˚C** and **+50 ˚C** can be achieved within **±2 ˚C** accuracy
- Thermal Capacity of the test room is **60 kW (± 5 kW)**
- Maximum radiator length is **4 metres**
- Maximum number of radiator sections is **30**
- Cooling **fans** and **pumps** can be added
- **Natural** and **forced** convection can be simulated and tested

Test Room

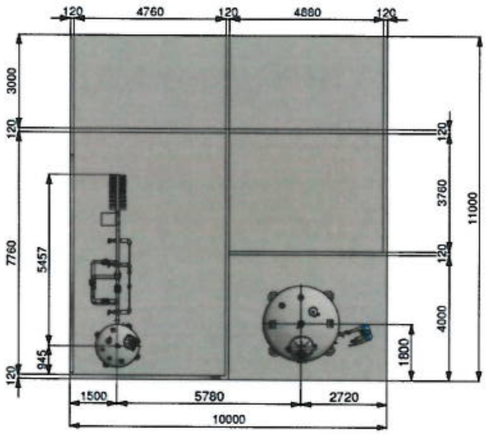
3D Model

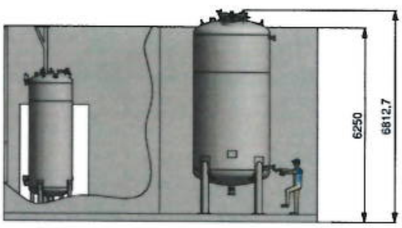
- Test room will be equipped with control room where the flow and temperature settings for the room, chiller group and tanks are controlled.
- All the readings from temperature and flow sensors will be recorded into a PC.



Test Room

Test Room Dimensions





Measurement Systems

Temperature, Pressure and Velocity Measurements

- **Fiber optic sensors** will be used to determine the air side convection coefficients.
- The readings will be obtained from the top, middle and the bottom of the radiator section.
- Readings will be provided for every radiator section for forced and natural flow.
- The average values will be computed to calculate the **average convection coefficient**.
- **Test room temperature** will be measured from 20 points and will be used to control the test room temperature.
- **6 PT100 temperature sensor** will be used to measure the oil temperature.
- Oil flow will be increased/decreased with **variable speed pumps**.
- Pressure at the inlet and outlet of the radiator will be measured by **pressure gauges.**

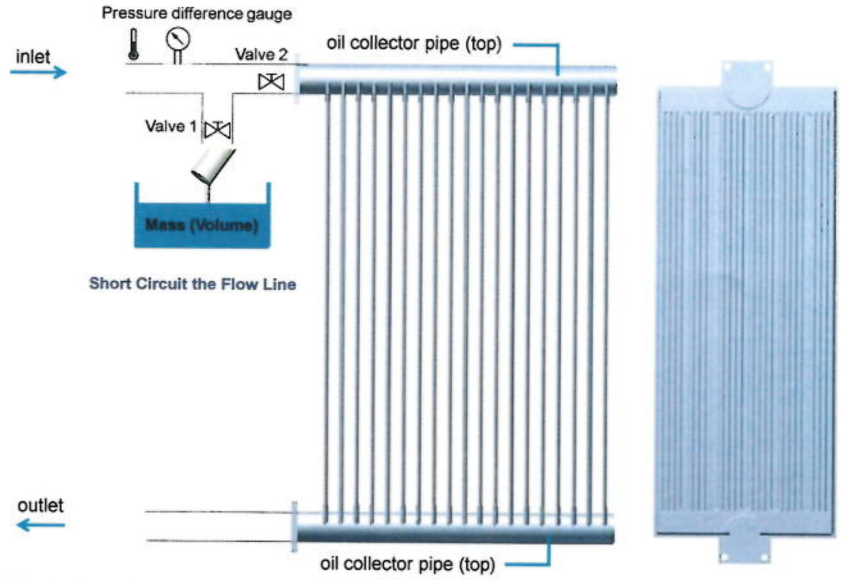
Measurement Systems

Velocity Measurement in Natural Flow

- A challenge is to measure the inlet and outlet **velocity** at natural flow conditions.
- Velocities are **extremely slow at natural flow**, close to creep flow
    - First, pressure drop and temperatures along the radiators will be measured.
    - Inlet to radiators will be closed and a second valve will be opened.
    - This new valve will allow oil to flow into a container (Short Circuit the flow line).
    - By adjusting the valve, same pressure drop will be generated.
    - For a certain period of time, the oil will spill into the container.
    - Weight and temperature of the oil will be measured.
    - Inlet and outlet density can be found.
    - Using continuity equation both inlet and outlet velocities can be determined.

Measurement Systems

Velocity Measurement in Natural Flow



Thank you.