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THERMO-STRUCTURAL ANALYSIS OF STEAM TRACING ARRANGEMENTS APPLIED TO PUMP BARRELS

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ABSTRACT

Pumps steam tracing is widely used in *Oil&Gas* industry for critical services in which the process fluid requires a minimum temperature to avoid its crystallization during stand-by. This paper describes the process of utilizing Computational Fluid Dynamics to perform a thermo-structural analysis of a barrel pump to determine the optimal steam tracing arrangement to maintain a minimum internal temperature. The most critical part of the analysis was to define the Heat Transfer Coefficient of the entire system. The computations consisted in conjugate Computational Fluid Dynamics solutions involving the ambient temperature and wind distribution, the skid dimensions and arrangement (barrels materials), the tracing system (carbon steel piping), the insulation (Mineral Wool) and the fluid compartments, both steam inside the piping and air in the gaps. The steam was modelled as a single-phase fluid with properties defined to consider the latent heat of condensation.

INTRODUCTION

In almost all manufacturing and refining processes, the temperature of the media is a key factor, but there are lots of services for which the temperature control of the process fluid remains a critical factor. The simplest situation is during the winter season, when the extremely cold temperature can fall below freezing levels and the ice expansion can damage pipes or equipment. Even in the absence of freezing temperatures, the heat lost towards the ambient can lead to undesired situations. For the steam, the dryness fraction lowers as more heat is lost. In certain cases, the heat lost can be dangerous for the equipment since process media can crystallize and differently from freezing there's no way to reverse the process.

When this occurs, process media is kept within a specific temperature range (heat loss is mitigated) in two ways: heat tracing and/or thermal insulation. The former applies an external heating source, the second acts as a barrier to the dissipation.

Heat tracing commonly found in process facilities, such as refineries or chemical plants, are electrical and, more often, steam tracer lines are the tubing that carries the steam alongside the process pipe and the equipment.

Typical applications for steam tracing include:

- Low- or slow-flow piping sections such as branch connections from parallel heat exchangers or pumps, or bypasses around equipment
- Equipment or piping that needs to be kept warm due to low ambient temperature conditions
- Suction piping of a gas compressor from the outlet of the upstream KO drum (to prevent condensation)
- Inlet piping of relief valves (to keep the piping and valve interior free of any precipitating materials or crystallized hydrates)

Steam tracing is commonly used to:

- Prevent process media from solidifying due to wax separation, crystallization, and water freezing
- Maximize plant efficiency, as instrument bridles and external piping to the process are inherent heat sinks
- Maintain the fluidity of viscous products during shutdown or in isolated piping
- Avoid fluid-component separation caused by low temperatures
- Prevent freezing of process media that contain water
- Prevent condensation of gaseous process fluids
- Prevent pipes from being damaged by very cold ambient temperatures
- Prevent formation of hydrates or related compounds as scale in pipes due to low temperatures

Inefficient heating processes can slow down production, costing time and money. Damages caused by freezing temperatures or improper heating are a painful mistake. Heat trace systems are built to make sure that mistake is never made.

The purpose of this article is to provide sufficient information to understand the basics of heat trace and its components and review best practices in the design of a steam tracing system.

Aim was to finalize the heat tracing with steam tubing to control the temperature in any transient situation. The request was made in an advance stage of the project. Due to late design phase, the strict customer specification, critical services and harsh operating condition, the tracing design required special attention. The development of the geometry of the tracing system required a study due to the geometric constraints (the pumps skids were almost ready).

HEAT SYSTEM DATA AND DIMENSIONS

A geometry with ring manifolds at the ends of the barrel and longitudinal tubes along its length has been developed to ensure the greatest possible coverage but at the same time to guarantee accessibility for the pump maintenance (see Figure 1).

The project involved 3 pump trains defined in Table 1:

	Pump Type	Barrel Material class	Minimum metal temperature [°F (°C)]
HP Lean Amine Pump	6x15 DDHF/6stg	S-6	140 (60)
VR Feed Pump	6x13 DDHF/9 stg	A-8	266 (130)
Short Circulation Pump	4x12 DDHF/9 stg	S-6	176 (80)

TABLE 1: BB5 pump trains with each barrel material class and minimum metal temperature

The materials of the barrels analyzed were S-6 and A-8 and the holding temperature ranged from 140°F to 266 °F.

The tracing system can be schematized by the Table 2:

	N. of Tubes	Length [in (mm)]	Tubing size	Material
HP Lean Amine Pump	30	65 (1640)	½"	Carbon steel
VR Feed Pump	32	101.5 (2579)	½"	Carbon steel
Short Circulation Pump	20	64 (1622)	½"	Carbon steel

TABLE 2: Tracing system scheme and size

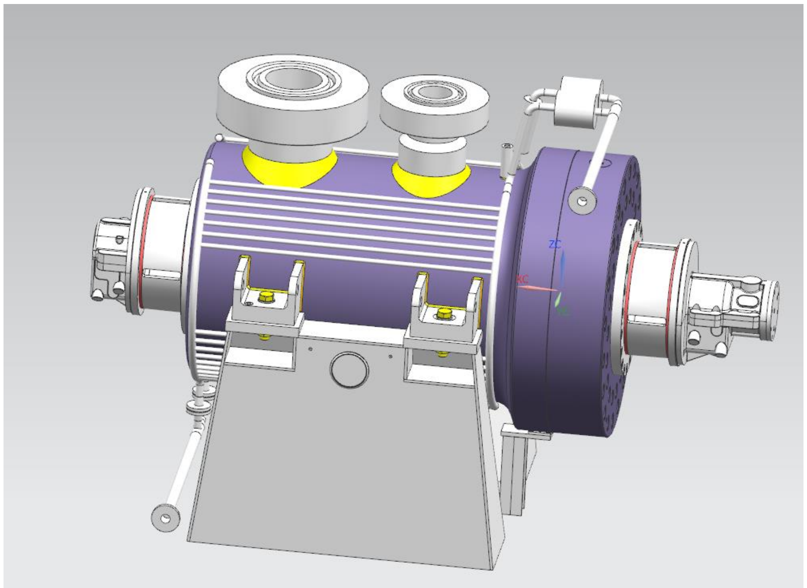

FIGURE 1: Pump heat tracing

After being traced, the casing, including vent, drain and warm up lines, was insulated with stone wool blanket with 4 inches thickness. The criticalities of the operation, the atmospheric condition with high wind speeds and the need to design the steam tracing at an advanced stage of design with important geometric constraints, prompted us to make more precise calculation on the thermal dispersion and on the steam flow rate necessary to ensure the operability of the pumps.

NUMERICAL MODELLING

All the simulations were performed with Ansys CFX 2019 R3 and in a steady state, namely rating the conditions after an infinitely long time. This represents the most severe and conservative case, in which the thermal inertia is neglected.
The computational domain is depicted in Figure 2a (showing the pump barrel and the surrounding environment) and Figure 2b (showing in detail the components of a typical pump barrel).

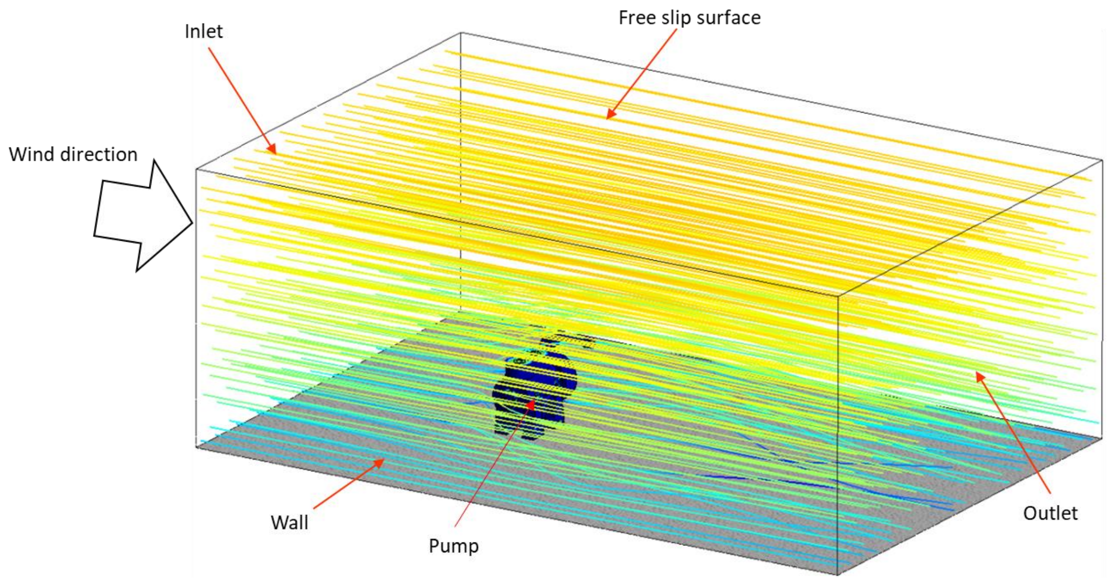

FIGURE 2a: Typical computational domain – pump barrel and surrounding environment

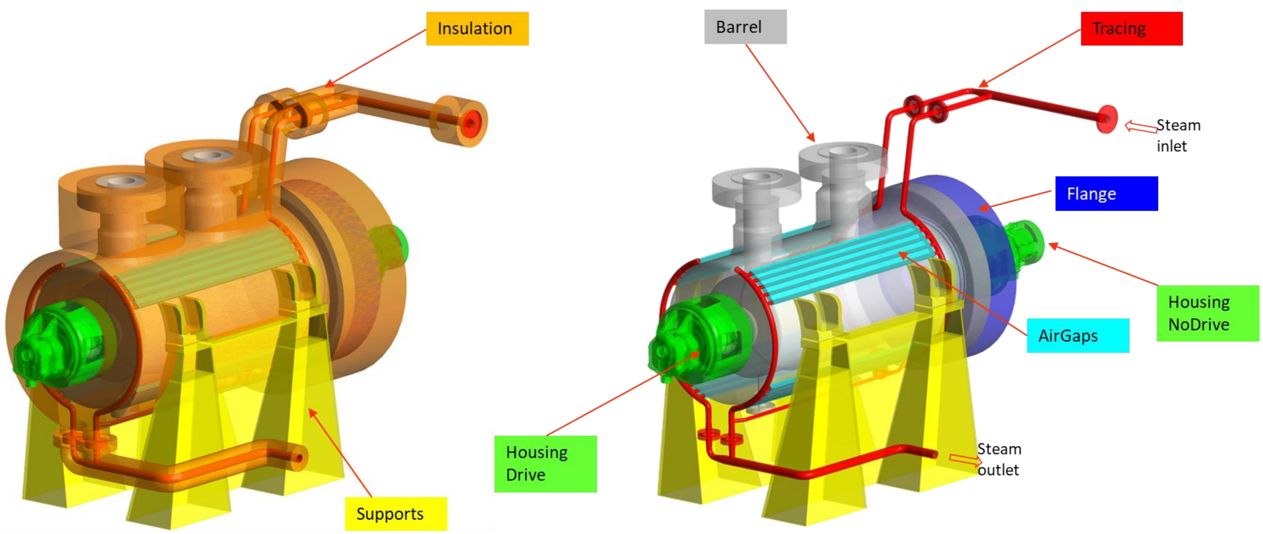

FIGURE 2b: Typical computational domain – pump barrel and detail of its component

The air was modelled as an ideal gas with temperature-dependent properties. The solid components were modelled using tables to describe the thermal conductivity of each material as a function of local temperature. After a preliminary assessment, the internal region of the turbopump was not included in the simulations, thus removing both shaft and casing, as well as the internal liquid. This assumption allowed to reduce the computational effort by neglecting the complex fluid dynamics of the still liquid subject to buoyancy.

Turbulence effects were modelled with a RANS approach by means of the k-ε model, with the near-wall flow modelled with scalable wall functions, and buoyancy effects were included in the simulation. The cases were set to perform a Conjugate Heat Transfer (CHT) analysis to resolve the heat transfer through the interfaces with the boundary conditions $T_1=T_2$ and $q_1=q_2$, where 1 and 2 represent the two sides of the CHT interfaces (fluid-solid or solid-solid). All contacts between solids were considered ideal (without a thermal contact resistance).

The modelling of the steam needs a separate discussion. The operating conditions of the heating system based on steam flowing through the tracing leads the superheated steam to condense along the way, being collected as a liquid on the bottom. To avoid dealing with the two-phase heat transfer and the phase change process, the fluid was modelled as a single-phase metafluid with increased specific heat capacity to achieve a nearly constant temperature throughout the tracing. This assumption can be considered precautionary, as the beneficial effect of the sensible heat is neglected. The results were then verified by considering the temperature of the internal surfaces of the barrel, i.e. those in contact with the processed fluid.

As far as the boundary conditions are concerned, to avoid any uncertainty associated with an estimate done by a correlative approach, the external environment was fully resolved by means of CFD. It was characterized by a lateral crosswind at 57.2 ° and a velocity profile described by the 1/7th power law, calculated to achieve 40 ft/s (12 m/s) at z = 33 ft (10 m) (see Figure 3). The conditions of the steam were expressed with an inlet velocity and a temperature at the inlet of the tracing (V_{in} = 0.82 ft/s (0.25 m/s), T_{in} = 393.8 °F (201 °C)), while prescribing a static pressure at the outlet (P_{out} = 206 psi (14.2 barg)). It is worth underlining that the inlet temperature does not correspond to the real temperature of the steam, but to its saturation temperature, because, as already mentioned, the contribution of sensible heat is neglected.

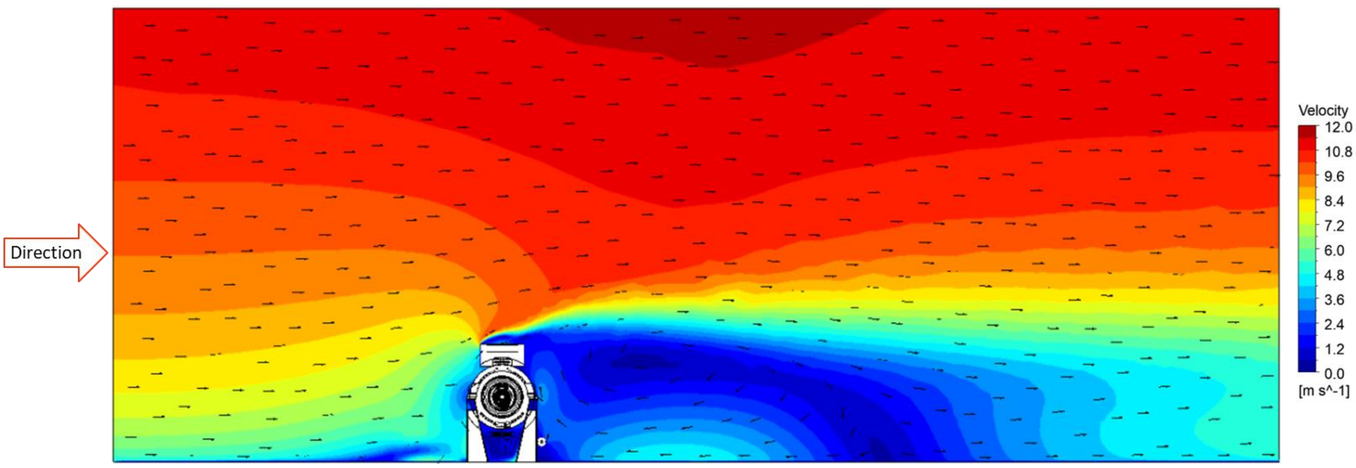

FIGURE 3: Typical velocity field surrounding the barrel

The computational grids were generated in Ansys Meshing and consisted of tetrahedrons, with a layer of 10 prisms on the surfaces of the air and steam domains. The typical mesh counted between 45 and 50 million elements.

RESULTS

The first results showed (Figure 4) an incomplete uniformity of the temperature reached in the barrel in some of the cases and the difficulty in increasing the temperature of the barrel, despite the increase in the steam flow. This is because, due to geometric constraints, the distance between the tracing tubing and the barrel was not negligible and the low conductivity of the air in this same meatus did not guarantee an efficient heat exchange. In addition, a high heat dispersion was evident on the bearing housing and on the supports, the only parts of the pump not affected by steam tracing and thermal insulation.

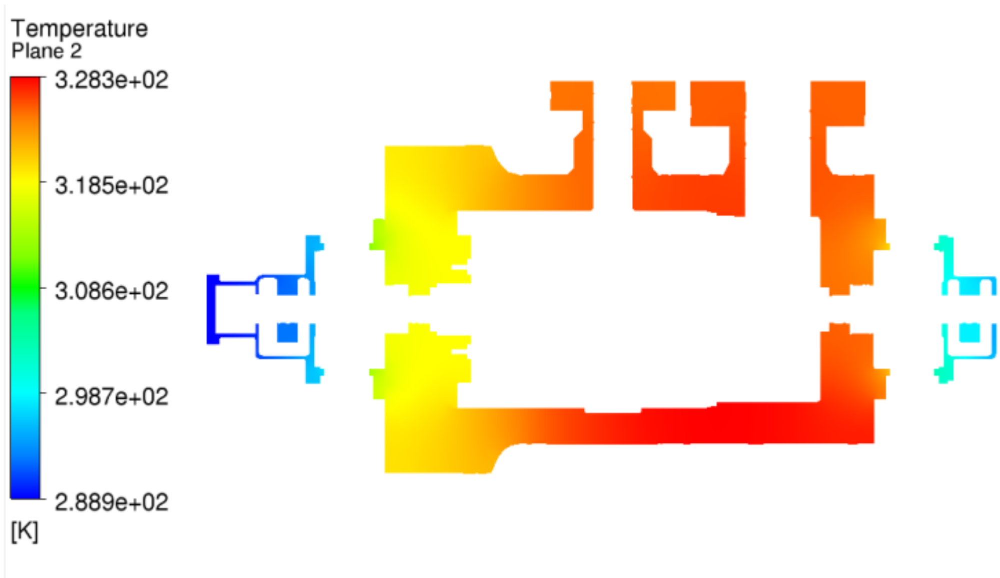

FIGURE 4: Temperature gradient contour in meridional section of the barrel

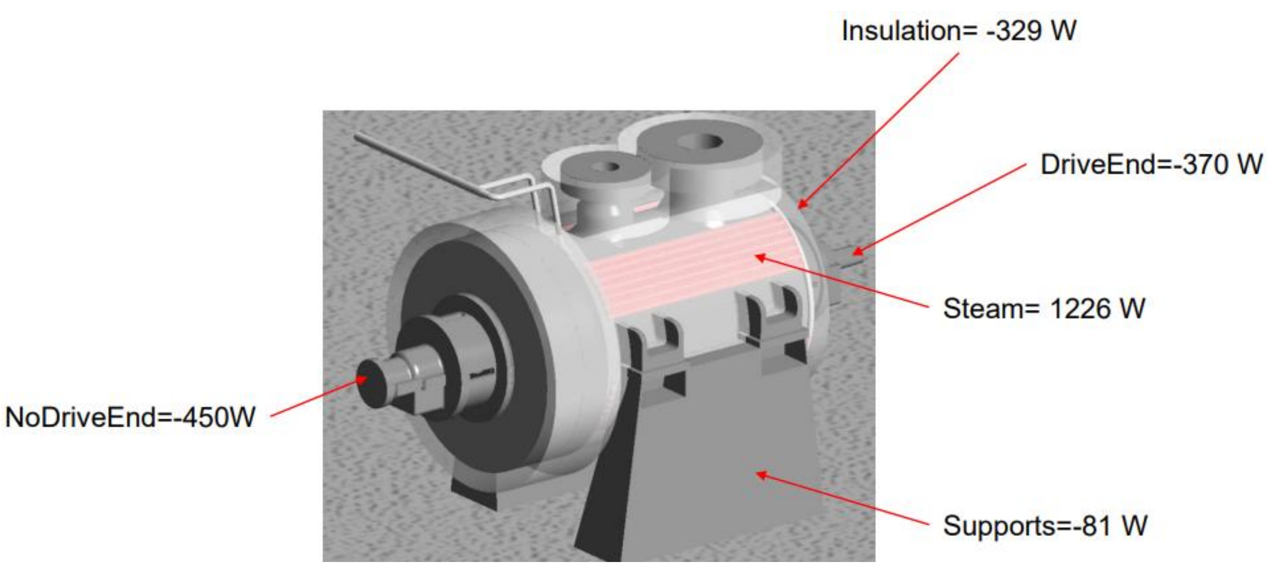

FIGURE 5: Power dispersion trough supports and bearing housings

Dispersions through the supports and bearing housings cannot be avoided as the areas must be free and accessible, therefore the solution undertaken concerns the possibility of improving the heat exchange between the steam tubing and the pump barrel.

The simulations were then carried out taking into consideration the possibility of applying a thermal compound creating an efficient thermal bond between the steam tubing and the equipment. This option was effective as can be seen from the Figure 6.

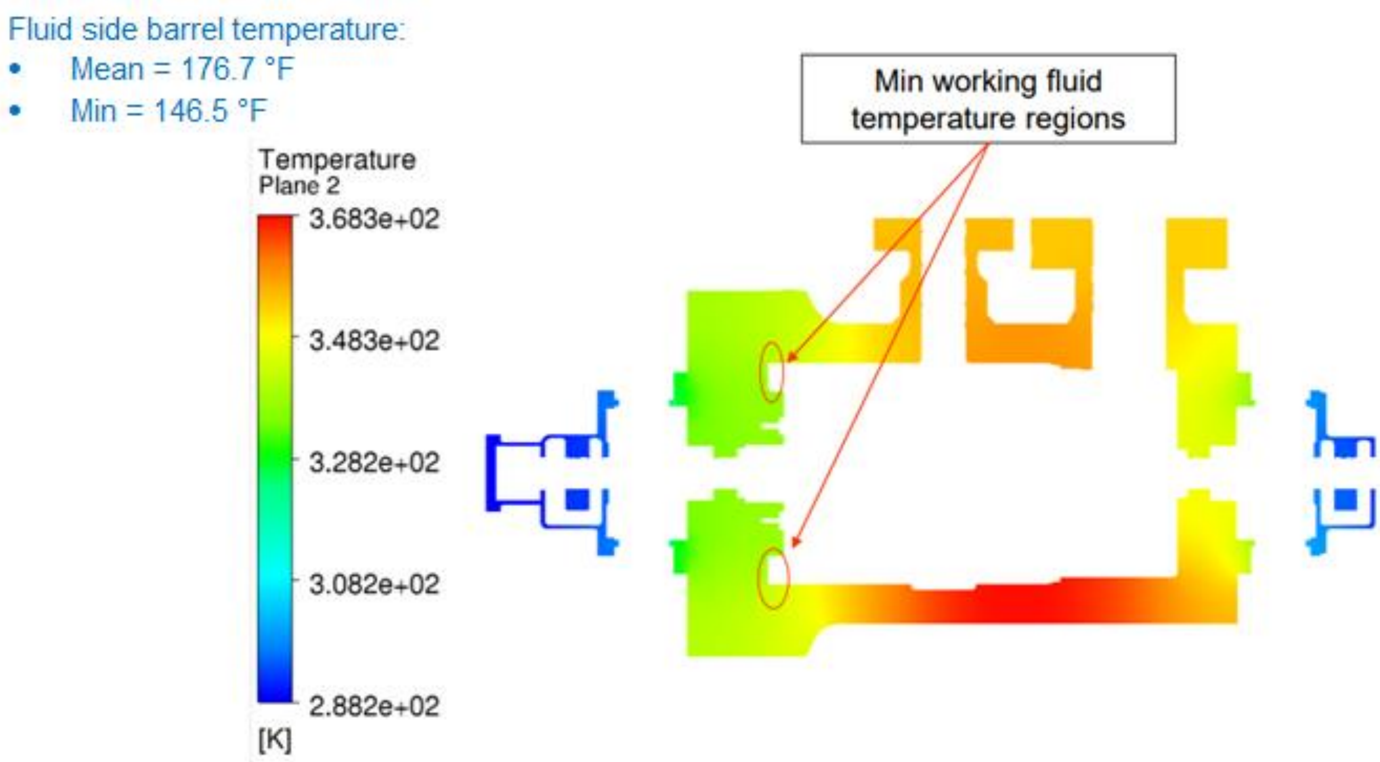

FIGURE 6: Temperature gradient contour in case of thermal compound usage

CONCLUSIONS

The difficulty of creating a steam tracing on already finalized skid, therefore with particularly important constructive constrains, prompted us to deal with a more accurate numerical analysis. The most critical part of the analysis was to define the Heat Transfer Coefficient of the entire system considered and its schematization to balance the approximation of the reality with a reasonable computational effort. As boundary conditions in the numerical analysis are set the flanges and drain/vent lines surfaces as adiabatic, as well as the inner profile of the barrel and the bearing housing; the rest of the surfaces are set as interfaces between the profile and the enclosure, the casing with the stone wool blanket, supports surfaces with external enclosures, the air gap meatus with barrel and the insulation blanket, as shown in Figure 7a-7b.

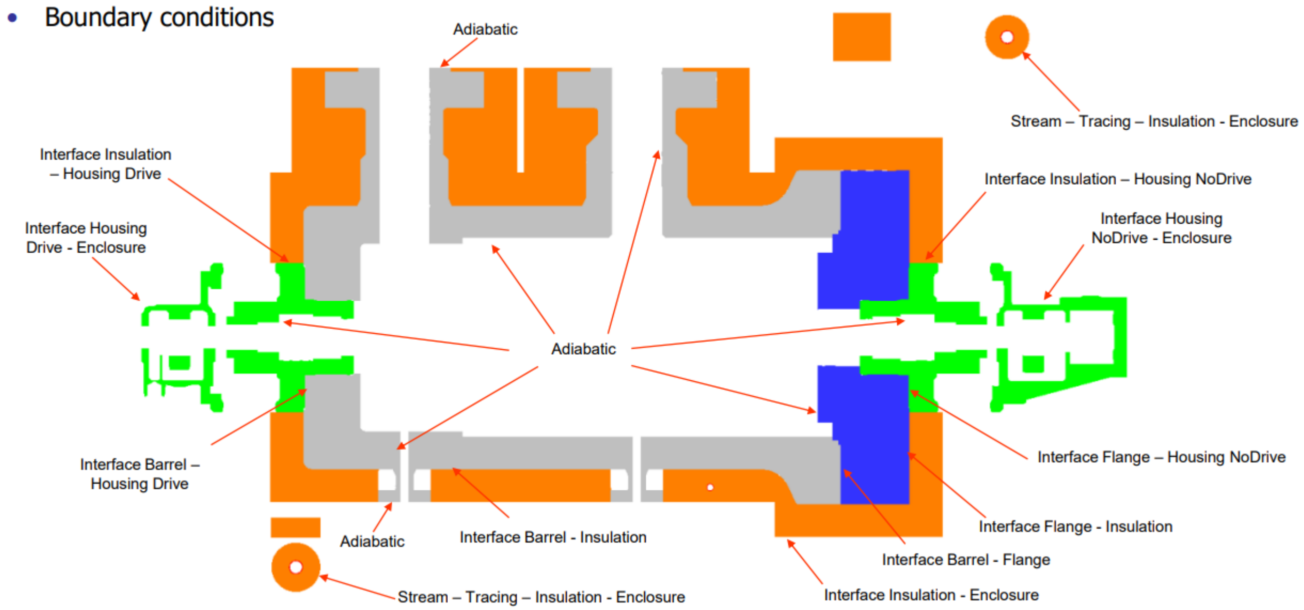

FIGURE 7a: Boundary conditions for numerical simulations

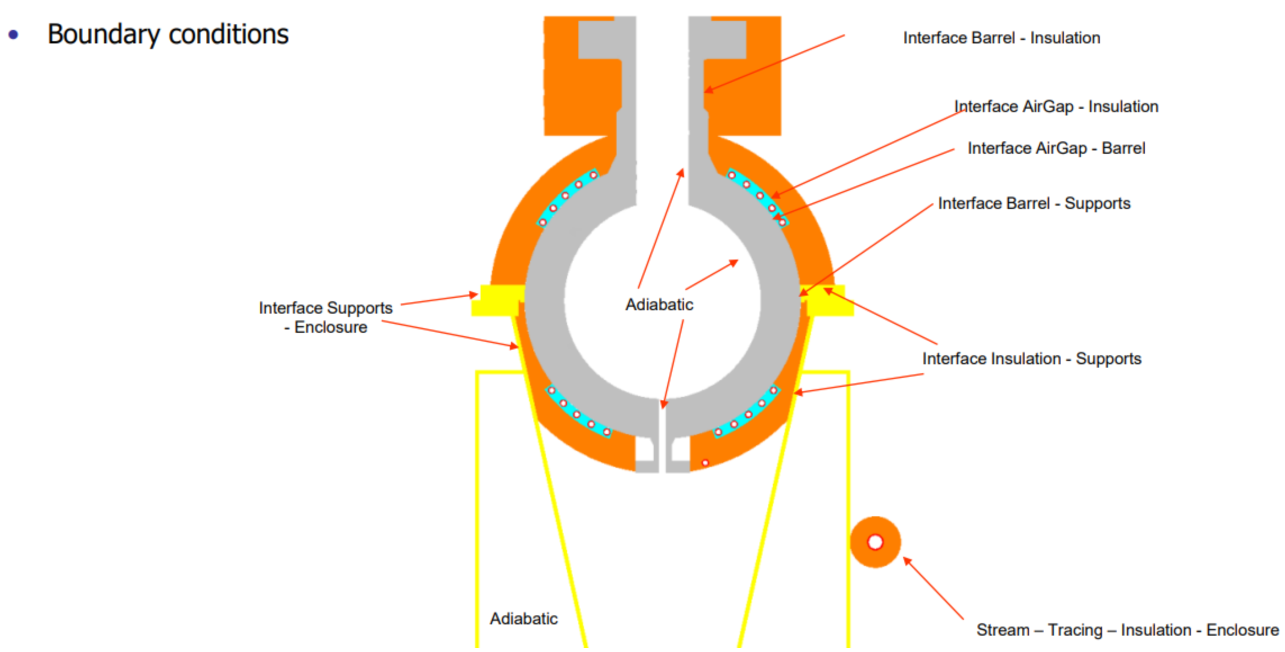

FIGURE 7b: Boundary conditions for numerical simulations

The actual difficulty of heating the barrel uniformly with variable section and the impossibility to insulate the pump ends and to bring the steam path close to the outer surface of the barrel, led us to use a thermal compound with a thermal conductivity better than that of air. The numerical results showed a decisive improvement in the effectiveness of the exchange, allowing us to address customer requests.

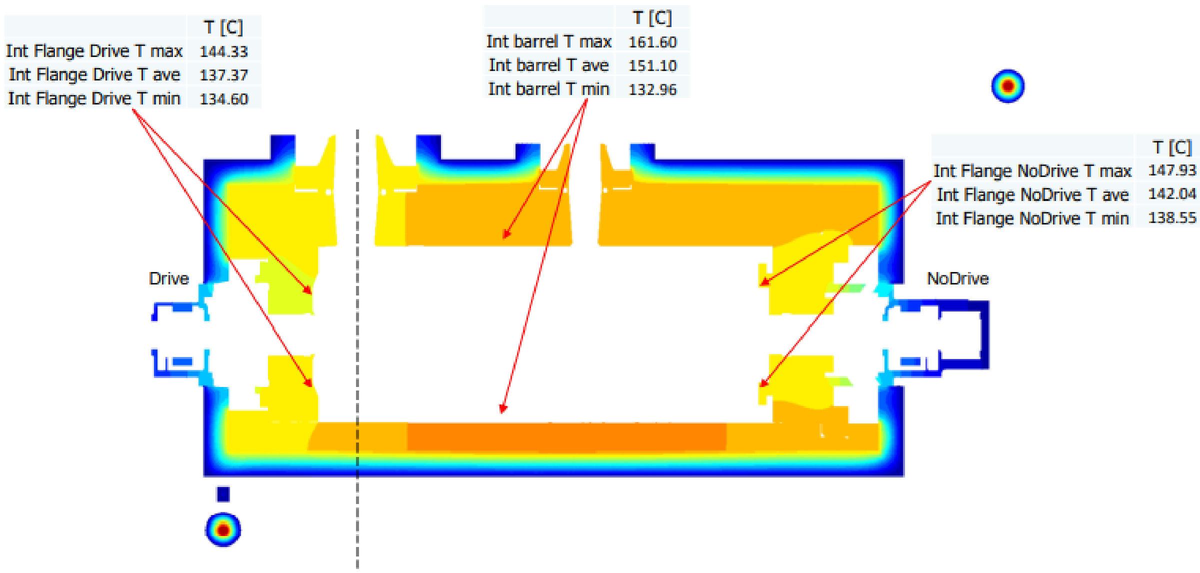

FIGURE 8a: Results for VR Feed Pump

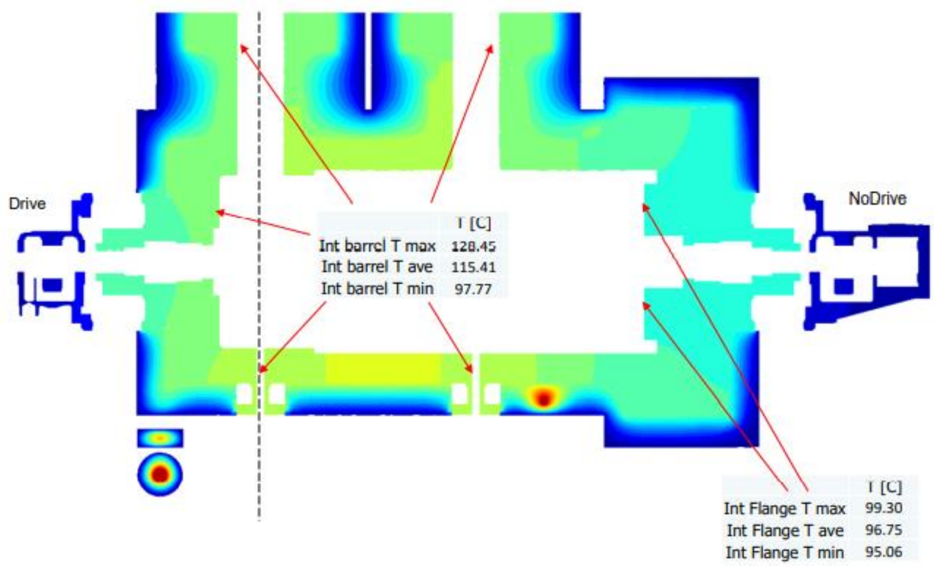

FIGURE 8b: Results for Short Circulation Pump

NOMENCLATURE

KO drum = Knock-out drum
CHT = Conjugate Heat Transfer
DDHF = Double casing pump for Hot fluid application
BB5 = Between Bearing multistage double casing pump.

REFERENCES

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NX siemens Thermal Analysis User's Guide.