Heat Loss Distortion of Scale-Downed Integral Effect Test Facility

Sung Deok Hong, Won Pill Baek
Korea Atomic Energy Research Institute, Yuseong-Gu, Daejeon, Korea, 305-600
sdhong1@kaeri.re.kr

1. Introduction

Heat losses of a scale-downed integral effect test facility are relatively increased because Heat Transfer Area (HTA) is much expanded than a prototype's. The HTA distortion can be divided into "ideal distortion" and "practical distortion." In case of the 1/288 volume scaled and 1/2 reduced height ATLAS facility constructing in Korea Atomic Energy Research Institute, the scale-down brings the relative expansion of HTA about 8.5 times greater than prototype's by the ideal distortion. The practical distortion makes an additional increase of HTA. The sources of practical distortion are the relatively extended thickness of pipes and insulations, the increased number of mechanical junctions, uniformly distributed instrument penetrations, random supports of components and steam leakages of some connections. Heat loss distortion can be mitigated by selecting high performance thermal insulators and avoiding instrument local cooling. But a tracer heating system could be a useful solution to compensate for unavoidable heat loss of test facility. In this paper, we discuss study results of the various sources of the HTA distortion, the calculation methods and heat loss results of ATLAS facility.

2. Ideal distortion

The HTA distortion of test facility depends on a scaled volume and a scaled height. The ideal distortion is

$$F_{Ideal} = \frac{H_m}{H_p}\sqrt{\frac{V_p}{V_m}} \ . \qquad (1)$$

Most of test facilities are greatly reduced to their volume scales, but slightly or not reduced their height scales. Therefore, the equation (1) cannot be unity and an ideal distortion always exists on every integral effect test facility.

3. Practical distortion

3.1 Thickness effect

The 2mm is a scale downed reactor vessel thickness in case of ATLAS. But to endure a full pressure and temperature, the scale downed thickness should be changes to 50mm. The extension of the thickness is enlarged the HTA of reactor vessel to 125%. The thickness of component insulation brings about same kind of a distortion. We can define *Thickness Distortion Factor* (TDF) as follows;
for a pipe,

$$F_P = \frac{d_O}{d_I + 2t_s} \qquad (2)$$

where t_s is scale downed ideal pipe thickness.

For overall thickness after insulation,

$$F_{IS} = \frac{d_O + 2t_{insulation}}{d_I + 2t_s} \ . \qquad (3)$$

3.2 Instrument penetrations

The instrument penetrations to measure absolute pressure, water level, fluid and wall temperatures are uniformly distributed on the primary components. The shape of the instrument penetrations is similar with the shape of cylindrical fin. Considering radiation and convection, the heat loss in a fin section becomes [1]

$$q_{Fin} = q_C + q_R = mkA_{CX}T_{Loop}\Psi \qquad (4)$$

where m is the fin coefficient and Ψ is the radiation correction factor,

$$\Psi = \sqrt{1 + 4\frac{\Re T_\infty^3}{h}\left[1 + \frac{T_{Loop}}{T_\infty} + \frac{1}{2}\left(\frac{T_{Loop}}{T_\infty}\right)^2 + \frac{1}{10}\left(\frac{T_{Loop}}{T_\infty}\right)^3\right]} \ .$$

A precise calculation of Ψ is difficult because of the uncertainty estimating the radiation coefficient.

3.3 Mechanical junctions

Most of mechanical junctions of the experimental facility are flanges. Generally a pair of flanges is placed in upper and bottom parts of the vessel. The shape of the flange can simplified an annular ring sitting on a pipe. The flange heat loss is

$$q_{Flange} = 2\pi\delta k T_{Loop}\Phi \qquad (5)$$

where δ is flange thickness and

$$\Phi = -Mr_1 \frac{I_1(Mr_1)K_1(Mr_2) - I_1(Mr_2)K_1(Mr_1)}{I_0(Mr_1)K_1(Mr_2) + I_1(Mr_2)K_0(Mr_1)}$$

where I_0, I_1, K_0, K_1 are modified Bessel functions.

3.4 Support & steam leakage

Various supports of components and steam leakage through the connections are additional heat loss sources. The shape of support can be simplified or lumped to a fin for heat loss calculation [2]. It is not easy to quantify the amount of heat loss through the steam leakage without measurements.

4. Results and discussions

The ideal heat loss distortion of a test facility is an inherent distortion and increases as scale downed as a prototype. For small pipes, the importance of thickness distortion is much increased as shown in Figure 1. When the insulation thickness is fixed to 30mm, the overall TDF is greatly increased as the pipe size decreased. The higher TDF leads to the higher conduction heat loss. Table 1 shows the heat loss calculation results for ATLAS. The prime heat loss source is conduction where 21.4kW (44.5%) of heat are lost. The amount of heat losses through the instrument penetrations (sensor lines) comes out 5.4%. It is less than half of the various supports. The heat losses through the mechanical connections (flanges) are calculated as 34.3%. The amount of practical heat losses figure out the sum of the heat loses from the flanges, sensor lines, supports and some part of the conduction and the nozzles (thickness effect). In case of ATLAS, the practical distortions without including the thickness effect of pipes and nozzles are occurred to 51% of total heat loss.

5. Conclusions

We have drawn the following conclusions;

1. Structural heat transfer area is increased by both *ideal distortion and practical distortion*

2. For small pipes, the importance of thickness distortion is much increased owing to the relatively large *thickness distortion factor*

3. For ATLAS, the practical distortions except the thickness effect are occurred to 51% of total heat loss

Nomenclature

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A_S	Surface area [m²]
A_{CX}	Cross section area [m²]
d_I, d_O	Pipe inner and outer diameters [m]
F	Distortion factor
h	Heat transfer coefficient [W/m²/°C]
H_m, H_p	Model and prototype heights [m]
k_S, k_I	Steel and insulation thermal conductivities [W/m/°C]
L	Vertical or horizontal length [m]
m, M	Cylindrical and annulus fins coefficients
P	Perimeter [m]
$\mathfrak{R}$	Radiation coefficient [W/m²/K⁴]
T_{Loop}, T_∞	Loop and ambient temperatures [°C]
V_m, V_p	Model and prototype volumes [m³]

REFERENCES

[1] P. J. Schneider, "Conduction Heat Transfer," Addison-Wesley, 1955.

[2] J. Sanders, " Heat Loss Tests for the LOBI-MOD2 Facility," Commission of the European Communities, Ispra Establishment, EUR 6539 EN, 1986.

Table 1. Heat loss calculation results for ATLAS (Primary side only)

Source	Heat loss (kW)	Percents (%)
Conduction	21.4	44.5
Nozzles	2.2	4.6
Flanges	16.5	34.3
Sensor lines	2.6	5.4
Supports	5.4	11.2
Sum	48.1	100.0
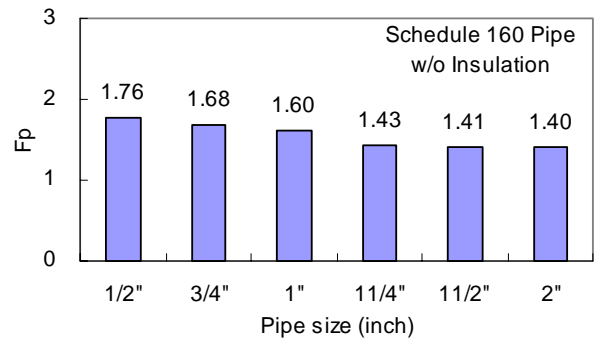
(a) Pipe TDF
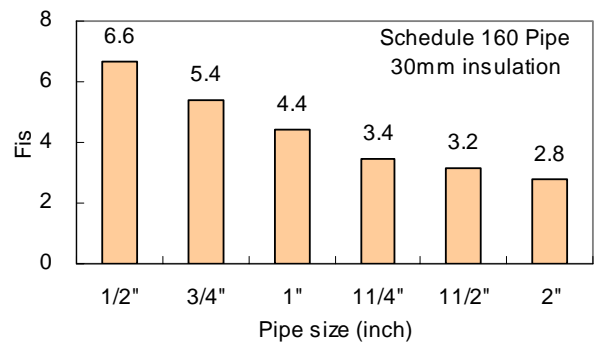
(b) Overall TDF

Figure 1. Thickness distortion factors along to the commercial pipe size