

## HEAT EXCHANGER LEAKAGE PROBLEM LOCATION

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**Abstract:** *Recent compact heat exchangers are very often assembled from numerous parts joined together to separate heat transfer fluids and to form the required heat exchanger arrangement. Therefore, the leak tightness is very important property of the compact heat exchangers. Although, the compact heat exchangers have been produced for many years, there are still technological problems associated with manufacturing of the ideal connection between the individual parts, mainly encountered with special purpose heat exchangers, e.g. gas turbine recuperators. This paper describes a procedure used to identify the leakage location inside the prime surface gas turbine recuperator. For this purpose, an analytical model of the leaky gas turbine recuperator was created to assess its performance. The results obtained are compared with the experimental data which were acquired during the recuperator thermal performance analysis. The differences between these two data sets are used to indicate possible leakage areas.*

### 1. INTRODUCTION

Modern heat exchangers are very demanding from the technological point of view. They are usually assembled from hundreds of parts made of various materials and joined together by various methods (e.g. mechanical bonding, welding, brazing) to form a heat exchanger core. The technology used when assembling the heat exchanger has the main impact on its performance in such cases in which the heat exchanger tightness is probably the most important parameter. Although, there is plenty of experience with very well tested technological processes for production of tight heat exchangers in huge series, there are still leakage problems with a heat exchanger produced for special purposes in small quantities. These heat exchangers have to be very well tested during the check-out process.

The problem of the leakage location inside the completed heat exchanger, based on the parameters measured during the performance tests, has been solved for the air to air heat exchangers used as a gas turbine recuperator or as a cooler in Environmental Control Systems (ECS) of a small aircraft or helicopters. A common feature of these heat exchangers is the high thermal efficiency and mainly the big pressure difference between air streams, which allows for determination of the direction of leakage mass flow.

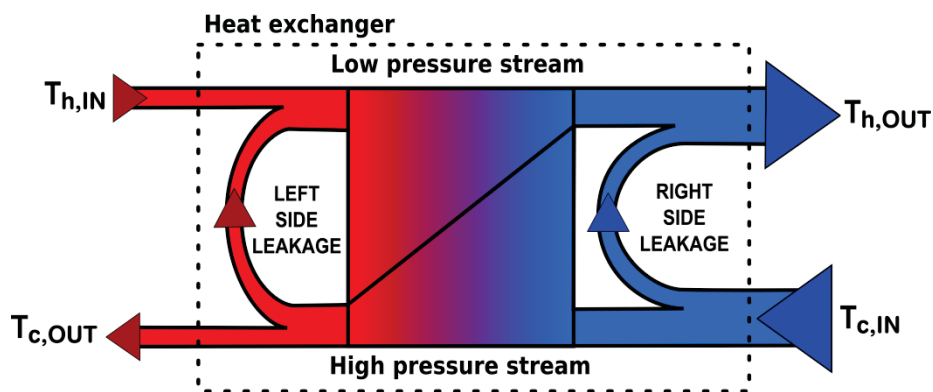
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## 2. NUMERICAL MODEL

1D numerical model of leaky heat exchanger behaviour has been developed for these types of heat exchangers. It is based on the amount of leakage (leak size) and it predicts temperatures of the media on both sides of the heat exchanger. The values obtained are thus directly comparable with the measured ones.

Well known  $\varepsilon$ -NTU method of heat exchanger sizing is used as the heart of the model. The mass flows corrected by leakage on the left and right side of the heat exchanger is used as an input to the model, see figure 1. The model also involves the inlet temperature correction, due to flows mixing, entering the model so that the proper solution has to be obtained by the iteration process.



**Figure 1. Schema of leaky heat exchanger**

The calculation of the heat exchanger performance is repeated for different leakage levels (escaping mass flows) and different leakage distributions between left and right side of the heat exchanger. All the processes could be described by following steps:

1. Select the amount of leakage (mass flow escaping from the high pressure flow stream)
2. Divide leakage to left and right side of heat the exchanger (chose the ratio from 100 % of leakage on left to 100 % on right)
3. Calculate the corrected mass flows and inlet temperatures on both sides (in case of the counter flow heat exchanger, it is necessary to guess high pressure stream outlet temperature, figure 1)
4. Calculate the thermal performance of the heat exchanger using  $\varepsilon$ -NTU and corrected values
5. Estimate the fluid flow outlet temperatures. Check the temperature assumption done in step 3.

It seems suitable to apply some type of normalization to the values obtained by the above mentioned procedure. An example of such normalisation is presented in the chart "Percent of leakage vs. Exchanger efficiency" in figure. 2.

The mathematical formula known from energy industry [1] is used to calculate the heat exchanger efficiency:

$$\eta = \frac{T_{c,OUT} - T_{c,IN}}{T_{h,IN} - T_{c,IN}} \quad (1)$$

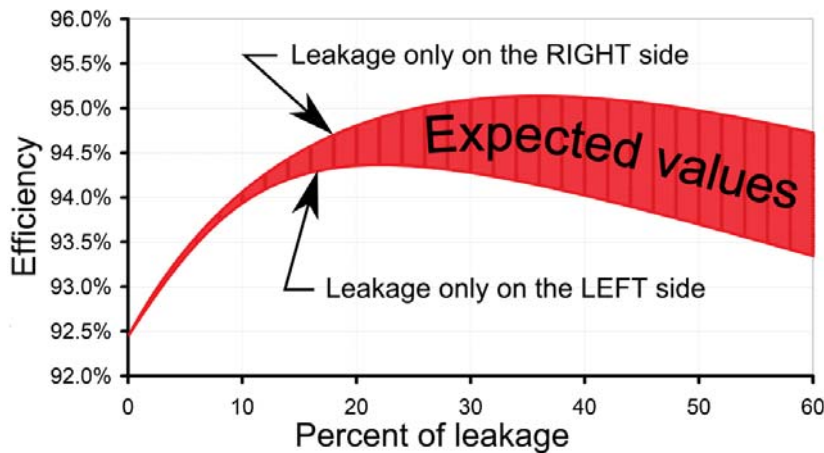
Where  $T_{c,IN}$ ,  $T_{h,IN}$  are the inlet temperatures of cold or hot stream and  $T_{c,OUT}$  is the outlet temperature of the cold stream.

For the Percent of leakage the follows equation is used:

$$\text{Percent of leakage} = \frac{\Delta\dot{m}_L + \Delta\dot{m}_R}{\dot{m}_{HP}} \cdot 100 \quad (2)$$

where  $\Delta\dot{m}_L$ ,  $\Delta\dot{m}_R$  are the leakage mass flows on the left and right side of the exchanger, respectively, and  $\dot{m}_{HP}$  is the total mass flow of the high pressure stream.

This type of "normalization" results in a map of the Expected values (Figure 2.), which describes the effect of leakage on the thermal performance of the tested heat exchanger. Moreover, it shows that the boundaries of the Expected values region stands for either the leaks occurring on the left or on the right side of the exchanger. Hence, it is possible to determine the leakage distribution inside the heat exchanger by additional measurements (e.g. outlet mass flow measurement for one of the fluid flows).



**Figure 2. Map of Expected Values**

### 3. PRACTICAL EXAMPLE

This model has been used to develop a suitable assembling technology for a gas turbine recuperator. The Expected values map was created for the leakages ranging from 0 to 60 % (Figure 2.) and the recuperator measured on the test rig. The output temperatures of both fluids (exhaust gas and air) have been measured and recuperator efficiency calculated from eq. 1, see Table 1.

**Table 1. Experimental values [2]**

	Reg. 1	Reg. 2
$T_{c,IN}$	189,5 °C	189,5 °C
$T_{c,OUT}$	426,0 °C	442,5 °C
$T_{h,IN}$	635,5 °C	683,0 °C
$T_{h,OUT}$	353,5 °C	364,5 °C
Efficiency $\eta$ (eq. 1)	51,3 %	51,2 %

The comparison of the obtained results (Figure 2. and Table 1.) show that the measured values are totally outside the expected values. Some of the trends derived from map of Expected values (Figure 2.) show that the recuperator leakage had to be very high but it does not correspond to the other results obtained (e.g. test turbine power). Hence, an assumption about the compressed air short-cut has been formulated based on those two facts. The assumption was later confirmed after disassembling the test recuperator. Based on this experience the recuperator construction was modified.

#### 4. CONCLUSIONS

The model of a leaky heat exchanger presented above should be used to determine the effect of leakage on the heat exchanger performance. This model is based on the conventional  $\epsilon$ -NTU method which employs the corrected mass flows and inlet temperatures as inputs. The model outputs for different leakage level should be "normalized" to create the Percentage of leakage against Heat exchanger efficiency chart, where the area of Expected values is formed. Hence this map of Expected values should be used to assess how the leakage is distributed inside heat exchanger, just from the values obtained during the heat exchanger thermal performance tests.

The greatest disadvantage of this method is that it is applicable only to limited types of heat exchangers, where the pressure of one fluid stream is substantially greater than the other one, so that the leakage direction is obvious.

So far this method has been evaluated during the development processes of a heat exchanger for small aircraft Environmental Control Systems and a gas turbine recuperator, where it helped to identify some critical issues of these heat exchangers.

#### 5. REFERENCES

- [1] HEJČÍK, Jiří. *Vysoce účinný rekuperátor spalín*. Brno: Vysoké učení technické v Brně. Fakulta strojního inženýrství. Energetický ústav. Odbor termomechaniky a techniky prostředí, 2009. 86 s. 3 přílohy, Ph.D. Thesis.
- [2] LINDOVSKÝ, P. *Měření parametrů voštinového rekuperátoru*. Velká Bíteš: PBS Velká Bíteš. Divize letecké techniky, 2008. 11 s. Technická zpráva. KDLT 533/08.

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