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### AN EVALUATION OF ENCAPSULATED OIL FLOODED SCREW COMPRESSOR SYSTEMS

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#### ABSTRACT

A study was carried out on oil injected compressors, to assess the value of compressor encapsulation in optimization of the compressor system and eliminating the need for an external oil separator.

The analysis was performed using a proprietary software suite for estimating the performance and optimising the design of a screw compressor, when it is subjected to a higher environment temperature, due to its containment in the oil separator. Several features were further investigated by use of 3-D computational fluid dynamics.

It was found that full encapsulation seriously worsens compressor performance. Accordingly it should be adopted only when justified by special circumstances. However, the semi-encapsulated compressors behave similarly to bare air ends. Thus, where they are cost effective, their adoption is to be encouraged.

**Keywords**: Screw Compressor, Design, Optimization, Efficiency, Reliability

#### INTRODUCTION

It is common practice today, in both refrigeration and air conditioning systems, to encapsulate oil flooded screw compressors within their oil separators. This is also becoming more common in air compressors. A study was therefore carried out, as part of a wider range of feasibility studies on oil injected compressors, to assess the value of this approach in:

Optimization of the compressor system.

Eliminating the need for an external oil separator.

The scope of the study included the following considerations:

A status review of screw compressorsencapsulated in oil separatorsA theoretical analysis of a compressor encapsulated in an oil separator

Full 3-dimensional numerical analysis of the oil flow

Recommendations for when it is appropriate to encapsulate a screw compressor in an oil separator.

The analysis was performed using a proprietary software suite for estimating the performance and optimising the design of a screw compressor, when it is subjected to a higher environment temperature, due to its containment in the oil separator. Several aspects, which were not included in the modelling assumptions of that suite, were further investigated by use of 3-D computational fluid dynamics.

One set of results for an encapsulated screw compressor is presented for a typical small oil flooded air screw compressor.

A CAD model of that compressor is also presented as an integral part of this study.

It was found that full encapsulation seriously worsens compressor performance. Accordingly it should be adopted only when justified by special circumstances. Semiencapsulated compressors behave similarly to bare air ends. Thus, where they are cost effective, their adoption is to be encouraged.

There is a long history of encapsulating screw compressors in their oil separators, especially in refrigeration and air conditioning systems, where they are described as hermetic and semi-hermetic screw compressors.



# Fig 1 Picture of encapsulated refrigeration screw compressor, Bitzer

A typical example of these, for small refrigeration compressors, is the Bitzer refrigeration compressor, shown in Fig. 1. This practice is becoming increasingly popular for air compressors, where, depending on a variety of factors, an encapsulated compressor may be more economical than an open one for smaller or special units.

Three different modes of encapsulation are considered in this paper. Thus the compressor may be:

1. Attached from outside to the oil separator, as in the case of the Tamrotor - Tempest, shown in Fig 2, Top. This arrangement is known as a semi-encapsulated compressor.

2. Attached inside the oil separator, as in many refrigeration compressors and in the Trudbenik air compressors, shown in Fig 1 Bottom a). This configuration is known as an encapsulated compressor.

3. Fully integrated into the oil separator, when the compressor body is machined directly in the oil separator, as for example in that of Rotorcomp, presented in Fig 2, Bottom

This concept is also described as an encapsulated compressor.





a) b) Fig 2 Representative encapsulated air screw compressors: Top: Tamrotor, Bottom a) Trudbenik, b) Rotorcomp

The advantages of encapsulated compressors over open units are as follows:

1. Machining and assembly of the compressor as well as of the oil separator is performed by the manufacturer under controlled conditions. Therefore, the resulting product must be better than if it is produced and assembled by different subjects at different places. This may therefore result in the most economical manufacturing solution.

2. A screw compressor encapsulated inside its oil separator will be quieter than an open one. Therefore it may run faster for the same noise level as an open compressor. This feature may also lead to a more economical solution.

A serious deficiency of the encapsulated compressor is the higher temperature of its environment, because in some arrangements, the compressor works inside the oil separator surrounded by hot oil. This deteriorates the compressor delivery and performance.

It therefore follows that the economy and performance of screw compressors, encapsulated in their oil separators, is highly dependent on the encapsulation configuration.

Configuration 1, which constitutes the compressor attached externally to the oil separator, is probably the most common arrangement and is very similar to a bare compressor block attached to an independently built oil separator. In such a case, the compressor behaviour is exactly the same as that of the bare air end. This, therefore, it does not require further performance analysis. This concept was chosen for the detailed design study and was used as the arrangement for oil separator 3-D analysis, as well as for constructing a 3-D model in Mechanical Desktop. Therefore, this detailed design can be used as a template for the extension of the same layout to other integrated compressors and oil separators.

Configuration 2 is similar to the first concept. However, since the compressor is encapsulated inside the oil separator, it may suffer from higher housing temperatures, which adversely affect the compressor performance. This concept was chosen as example, to show how the performance is calculated. A proprietary software suite for screw compressor performance calculation was applied here to quantify these effects. Therefore, any further calculation for other compressors and

**Bare Compressor** 

oil separators can be performed on the basis of this calculation template.

Configuration 3 comprises the complete machining of the compressor housing inside the oil separator. This has some of the features of the Configuration 2 and its characteristics lie somewhere between those of the first two arrangements. A decision on whether or not to use this will be highly dependent on the planned production volume, because it will require new castings, while the production of an integrated compressor will reduce demand for the basic bare unit.

### PERFORMANCE CALCULATION OF AN ENCAPSULATED SCREW COMPRESSOR

The compressor performance, when fully immersed in oil, was calculated. A standard version of SCORPATH (Screw Compressor Optimal Profiles and Thermodynamics) was applied to the encapsulated screw compressor to calculate its performance. The calculation was performed for ELGI 4/5-102 mm screw compressor. The calculation results of the encapsulated compressor which works within an oil separator of higher temperature were compared with the results of the performance calculations for a bare compressor block. An extract of the results is presented in Figure 3, where a comparison between the bare air end and the encapsulated compressor is given.

n	Flow	nv	Power	Spec Pow	n	Temp		
Rpm	m3/min	.1.	Kw	kW/m3/min	-1	°C		
1870	0.953	0.692	6.803	7.136	0.608	77.30		
2805	1.617	0.783	10.263	6.346	0.684	87.20		
3740	2.29	0.831	14.075	6.146	0.706	95.88		
4675	2.963	0.86	18.186	6.137	0.707	103.55		
5611	3.637	0.88	22.559	6.203	0.699	110.62		
6546	4.309	0.894	27.239	6.321	0.686	116.85		
7481	4.982	0.904	32.2	6.463	0.671	122.70		
8416	5.652	0.912	37.435	6.623	0.655	128.17		
Encapsulated Compressor							Drop in Pe	erformance
n	Flow	ηv	Power	Spec Pow	η	Temp	nv	n
Rpm	m3/min		kW	kW/m3/min		°C	enc/bare	enc/bare
1870	0.812	0.59	6.459	7.952	0.546	77.19	0.852	0.898
2805	1.466	0.71	9.855	6.723	0.645	90.08	0.906	0.942
3740	2.129	0.774	13.539	6.36	0.682	99.40	0.931	0.966
4675	2.793	0.812	17.492	6.262	0.693	107.6	0.944	0.980
5611	3.458	0.838	21.705	6.276	0.691	114.97	0.952	0.988
6546	4.123	0.856	26.182	6.35	0.683	121.6	0.957	0.995
7481	4.787	0.87	30.93	6.461	0.671	127.83	0.962	1.00
8416	5.45	0.88	35.959	6.597	0.658	133.60	0.964	1.00

## Table 1. Comparison of performance of encapsulated and bare compressor

They are also presented in Table 1. As can be seen, the efficiency of the encapsulated compressor only approaches that of the cold compressor at high tip speeds, where the performance of even the cold compressor is poor.

A full description of the model and its mode of calculation is given by Stosic et al,



#### Fig 3 Comparison of performance of the bare compressor and encapsulated unit

It can be seen from Figure 3 that the volumetric and adiabatic efficiencies are mainly affected in regions of lower compressor deliveries, especially the volumetric one. This calls for a conclusion that the encapsulation can not be recommended for compressors which will continuously work at low loads.

# 3-D CFD CALCULATION OF THE ENCAPSULATED SCREW COMPRESSOR

Following recommendation of the performance calculation, which confirmed that the best efficiency was achieved by a configuration which consists of a screw compressor combined with the oil separator, a full 3-D CFD calculation of a compressor integrated with the oil separator was performed to confirm the results obtained by the performance calculation program.

The oil separator interior geometry was modelled in Mechanical Desktop and was used as a basis for its presentation in Solid Works for further use in CFD calculations. It was then integrated with the 4/5-102 mm compressor to represent the encapsulated screw compressor unit as shown in Fig. 4. This truly represents geometry of the compressors in combination with the oil separator.

A 3-D CFD calculation of the compressor encapsulated in the oil separator was simulated by the use of the Star CCM software. The flow path of the separator was modelled in Solid Works CAD software. A polyhedral numerical mesh, corresponding to it, consisting of 56000 cells, was generated in the same software. A mass flow of 0.5 kg/s of air/liquid mixture at 7 bar and 70 deg C, with a liquid concentration of 10% by mass was set as the inlet condition to the separator. The outlet was set as a standard split outlet boundary. The case considered was run as steady state. The solution error was reduced by 4 orders of magnitude in 850 iterations. The case showed the separation of liquid and gas with the outlet liquid volume concentration in the gas to be less then 0.01%.

The solution was run on a multiprocessor PC with 2 GHz Xeon processors and 1GB memory.

A full description of the model and its modes of calculation is given by Kovacevic et al, 2006.

The polyhedral numerical grid was created by means of the Star CCM standard grid generator, from the Solid Works model. The generated polyhedral grid is presented in Fig 5.

The results of the calculation are presented in Figures 6 and 7, where the oil concentration and oil droplet traces are given respectively.

The results in Fig 6 confirm that the oil concentration was reduced for 4 orders of magnitude in the oil separator. This is a good indicator of quality of the separator design and construction.

The results in Fig 7 illustrate a flow path oil droplets and oil separation process.



Fig 4 CAD model of encapsulated air screw compressor and interior geometry of oil separator



# Fig 5 Polyhedral grid of oil separator



Fig 6 Concentration of oil in oil separator



Fig 7 Oil droplet traces in oil separator

### CONCLUSIONS

Screw compressors encapsulated in oil separators are becoming more widely used today, especially in small sizes, because of their practicality and economy. However, as is shown in this report, the performance of fully encapsulated compressors in air applications is significantly, adversely affected by this arrangement. It therefore follows that their use should be carefully analysed for each proposed application and then only adopted be applied only if the benefits can be shown to outweigh the disadvantages. Semi-encapsulated compressors behave similarly to bare air ends. Thus, if they produce economies in cost, their use is recommended. Compressors fully integrated into their oil separators may have advantages when they are to be mass produced.

The existing SCORPATH software, as already issued to ELGI, has the capability of calculating the performance of an encapsulated screw compressor. However the CFD facility used by Elgi should be upgraded to Star CCM to be capable of performing the calculations presented in this report. The Mechanical Desktop software suite is already used by ELGI. Therefore, the model of the screw compressor integrated with the oil separator, which can be downloaded at city-compressors.co.uk/integrated, can be immediately used for further applications and eventual modification by ELGI.

#### REFERENCES

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