

APPLICATION OF ORC UNITS IN THE MDF AND PARTICLEBOARD SECTOR - GENERAL CONSIDERATIONS AND OVERVIEW OF THE EXPERIENCES OF THE FIRST ORC PLANT IN THIS INDUSTRY INSTALLED AT MDF HALLEIN

Andrea Duvia – Turboden srl, V.le Stazione 23, 25122 Brescia – I- tel. 030-3772341, fax 030-3772346, andrea.duvia@turboden.it

Roberto Bini – Turboden srl, V.le Stazione 23, 25122 Brescia – I- tel. 030-3772341, fax 030-3772346, roberto.bini@turboden.it

Harald Spanring – MDF Hallein, Solvay-Halvic-Straße 6, A-5400 Hallein – A – Tel. 0043-624570500585, fax 0043-624570500121, harald.spanring@mdf-hallein.at)

Karl Portenkirchner – MDF Hallein, Solvay-Halvic-Straße 6, A-5400 Hallein – A – Tel. 0043-624570500585, fax 0043-624570500121, karl.portenkirchner@mdf-hallein.at

ABSTRACT: In the last 10 years the ORC technology applied in small size (0.5 –2 MW_{el}) CHP biomass plants has demonstrated to be a well proven industrial product with very good performances in terms of reliability, ease of operation, low maintenance requirement together with a good conversion efficiency allowing to implement cost effective plants.

In MDF production plants the heat request of the process is often covered partly or completely by large biomass boilers using waste material from the production process as fuel. The heat is used mainly as thermal oil for the presses and as hot combustion gases for fiber drying. The integration of the ORC in the MDF production process will be analysed in particular considering the possibilities for using the thermal power available downstream the ORC units inside the process, therefore obtaining an operation in CHP mode. The good economical results that can be obtained for a wide range of fuel and electricity values in full CHP mode are shown. The main process parameters and experiences of the first plant of this type realised at MDF Hallein near Salzburg – Austria since the start up in December 2005 are also discussed.

Keywords: Organic Rankine Cycle (ORC), Combined heat and power generation (CHP), Fibreboard

1 ORC units in Biomass cogeneration

In the last 10 years the ORC technology has demonstrated to be a well proven industrial product for application in small biomass CHP plants (0,5 – 2 MW_{el})

The typical system is based on the following main steps:

- Biomass is burned in a combustor made according to the well established techniques in use also for hot water boilers. These combustors with their set of accessories (filters, controls, automatic ash disposal and biomass feed mechanism etc.) are nowadays safe, reliable, clean and efficient.
- Hot thermal oil is used as heat transfer medium, giving a number of advantages, including low pressure in boiler, large inertia and insensitivity to load changes, simple and safe control and operation. Moreover, the adopted temperature (about 300°C) for the hot side ensures a very long life of the oil. The utilization of a thermal oil boiler also allows operation without the licensed operator required for steam systems in many European countries.
- An Organic Rankine Cycle turbogenerator is used to convert the available heat to electricity. Thanks to the ORC, that is thanks to the use of a properly formulated working fluid and to the optimisation of the machine design, both high efficiency and high reliability are obtained. The condensation heat of the turbogenerator is used to produce hot water at typically 80 – 120°C , a

temperature level suitable for district heating and other low temperature uses (i.e. wood drying and cooling through absorption chillers etc.) .

The ORC unit is based on a closed Rankine cycle performed adopting a suitable organic fluid as working fluid. In the standard units for biomass cogeneration developed by Turboden silicon oil is used as working fluid [1].

The thermodynamic cycle and the relevant scheme of components are reported in fig. 1.

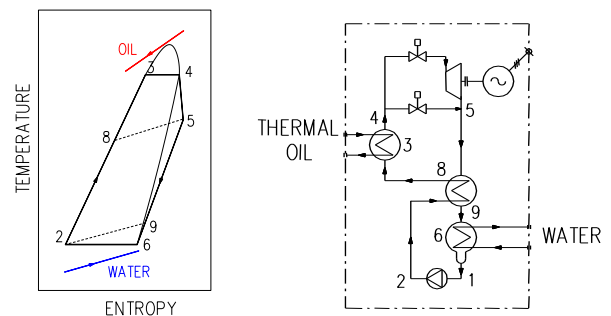


Figure 1 : Thermodynamic cycle and components of an ORC unit

The turbogenerator uses the hot temperature thermal oil to pre-heat and vaporise a suitable organic working fluid in the evaporator (8→3→4).

The organic fluid vapour powers the turbine (4→5), which is directly coupled to the electric generator through an elastic coupling.

The exhaust vapour flows through the regenerator (5→9) where it heats the organic liquid (2→8).

The vapour is then condensed in the condenser (cooled by the water flow) (9→6→1).

The organic fluid liquid is finally pumped (1→2) to the regenerator and then to the evaporator, thus completing the sequence of operations in the closed-loop circuit.

Compared to competing technologies, the main advantages obtained with this solution are the following :

- High cycle efficiency (especially if used in cogeneration plants);
- Very high turbine efficiency (up to 85%)
- Low mechanical stress of the turbine, thanks to the low peripheral speed
- Low RPM of the turbine allowing the direct drive of the electric generator without reduction gear
- No erosion of the turbine blades, due to the absence of moisture in the vapour nozzles
- Very long operational life of the machine due to the characteristics of the working fluid that unlike steam is non eroding and non corroding for valve seats tubing and turbine blades).
- No water treatment system is necessary.

There are also other advantages, such as simple start-stop procedures, quiet operation, minimum maintenance requirements and good partial load performance [2].

Due to these main reasons the standard range of ORC units developed, produced and marketed by Turboden Srl. Brescia is considered an optimal solution for small biomass cogeneration systems in the power range up to 2 MW_{el} per unit. This is confirmed by the 53 Turboden ORC plants in operation for a total installed power of more than 50 MW_{el} that are showing very good results in terms of reliability (average availability of the ORC units > 98% over more than 500.000 hours of operation) and low operational and maintenance costs.

2 Biomass energy plants in MDF production

In MDF production plants a substantial heat request exists in the production process. In a typical MDF plant the following heating media are used in the process :

- Low pressure steam for fiber preparation
- Hot gases for fiber drying in direct contact dryers
- Thermal oil for hot presses and other heat consumers

The process also generates a quantity of waste wood that is available from the following sources :

- Bark from the debarking system
- Low quality wood chips coming from the material preselection
- Waste wood and reject panels
- Sander dust

In most cases, depending on the input material to the process, the available wood that cannot be used directly as material for panel production reaches or even exceeds (in particular in case of plants using waste wood as material source) the quantity necessary for covering the heat requirements of the process. Therefore it is very common to use this wood directly in a suitable biomass combustion system designed for the supply of the required heating media to the process.

A typical design of these plants is based on a biomass combustion system with reciprocating grate and an additional injection burner for sander dust normally placed above the first combustion chamber [3]. A part of the flue gases is used in a thermal oil heater for the production of the thermal oil necessary for the presses. The steam for the fiber preparation is produced in an indirect thermal oil steam generator.

The remaining part of the flue gases goes directly to the "mixing chamber" where it is mixed with the gases coming from the thermal oil heater and with a stream of ambient air. The quantity of ambient air added is regulated in order to have a temperature of the gases after the mixing chamber compatible with the highest temperature inlet temperature acceptable in the dryer (usually about 180 – 200°C). Higher gas temperatures at dryer inlet would lead to lower fiber quality. The flue gas flow rate in the heater is controlled through a variable speed fan.

After the mixing chamber the flue gases are used in a direct contact dryer in order to dry the fiber up to the optimal moisture content for the following process stages.

The described process flow is represented with reference to a typical energy plant with process heat requirements of 20 MW_{th} in the dryer and 20 MW_{th} for the thermal oil users (mainly presses and thermal oil steam generator) in Figure 2.

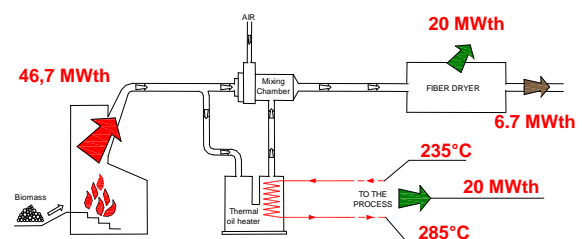


Figure 2 : Typical process scheme of Energy plant without electricity generation

Another usual design includes the installation of a direct steam generator in the flue gases after the thermal oil heater instead of the indirect thermal oil steam generator. The use of this alternative design solution has no significant effect on the technical considerations of the following chapters.

3 Cogeneration with ORC units in MDF plants

The MDF process also has a high internal consumption

of electricity mainly for the chipping and refining of the raw material. This makes the possibility of biomass CHP production particularly attractive not only in countries where subsidies for renewable energy production are available but also in countries where it just helps to reduce the electricity purchase costs for the plant own demand. This possibility has been seldom exploited in MDF plants due to the fact that biomass cogeneration systems based on the traditional steam process require high pressure generators that would lead to a complication of the process. Furthermore the typical size where steam plants are economically competitive (> 5 MW_{el}) leads in most cases to mainly non cogenerative process schemes because the available heat downstream the CHP plant is too high to be used completely inside the process.

The concept described in this paper is based on the use well proven standard ORC units fed by thermal oil that produce electricity and hot water at temperatures up to 120°C for further use in the process. The ORC technology is based on the use of thermal oil as heat carrier giving the possibility to implement cogeneration systems without significant changes to the well proven MDF process scheme. The main use for the hot water available downstream the ORC unit is the preheating of the air from ambient which is supplied to the mixing chamber. The typical size of standard ORC units is compatible with the heat load that can be used for this air preheating giving the possibility to implement a completely cogenerative operation mode.

3.1 Process scheme with ORC unit

With reference to the following Figure 3 the proposed process scheme is based mainly on the following additional components :

- An additional thermal oil heater placed in parallel to the main heater and to the flue gas bypass that leads directly to the mixing chamber .
- A standard ORC unit
- A hot water/ air heat exchanger used to preheat the air supplied to the mixing chamber.

Figure 3 illustrates the proposed scheme for a typical system with the same process requirements (20 MW_{th} for drying and 20 MW_{th} for process heat users) assumed for the base case reported in figure 2. The operating conditions allow to transfer about 7,7 MW_{th} to the ambient air before the mixing chamber in the case of a hot water temperature of 110°C at ORC outlet and a pinch point of 10°C in the hot water air heat exchanger. Assuming thermal oil temperatures of 300/250 °C at ORC inlet/outlet a net electric power of 1,45 MW_{el} can be produced by the ORC unit in completely heat driven operation (CHP mode).

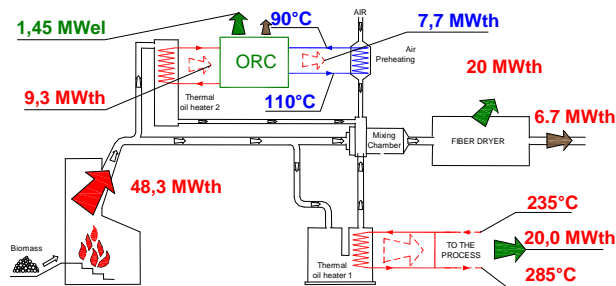


Figure 3 : Proposed scheme for energy plant with ORC cogeneration unit

3.2 Comparison of the CHP scheme with ORC unit with the traditional scheme

The insertion of the additional components necessary for the biomass cogeneration system is possible without significant changes in the design of the remaining parts of the system. This is shown in the following Table 2 where the technical characteristics of the main components of the traditional system and of the cogeneration system with ORC unit are reported. The main technical assumptions on which the comparison is based are reported in table 1.

Thermal power to process	20	MWth
Thermal power to dryer	20	MWth
Flue gas temp boiler	950	°C
Flue gas temp out T.O. heater 1	350	°C
Flue gas temp in dryer	200	°C
Flue gas out dryer	65	°C
Ambient temperature	20	°C
T.O. temp in ORC	300	°C
T.O. temp out ORC	250	°C
Hot water temp out ORC	110	°C
Pinch point in hot water / air heat exchanger	10	°C

Table 1 : Main technical assumptions

	Base	CHP	Delta	Delta %
Thermal power biomass furnace [MWth]	46,67	48,31	1,64	3,5%
Flowrate at biomass furnace outlet(*)	100,0%	103,5%	3,5%	3,5%
Thermal power to dryer	20	20	0,00	0,0%
Thermal power to thermal oil users	20	20	0,00	0,0%
Flowrate in TO heater 1 (*)	66,4%	66,4%	0,0%	0,0%
Mixing air flowrate	195%	192%	-3,5%	-1,8%
Florate in dryer (*)	295%	295%	0,0%	0,0%

(*)Flowrate in base furnace outlet = 100%

Table 2 : Comparison of base case and CHP system based on an ORC unit

The technical data of the thermal oil heater and dryer remain unchanged while a slight increase in the thermal power of the biomass combustion system (+ 4%) is necessary. This small change is often compatible with existing designs of the combustion chamber giving the

possibility to add the ORC unit also in existing systems if the plant layout allows the placing of the additional components. This means also that the cogeneration will be completely independent from the rest of the plant. The MDF process will maintain its operating parameters independently from the fact that the ORC is in operation or not. The result is that the introduction of the ORC system will have almost no impact on plant operation and availability, as well as on overall plant control procedures.

The comparison of the energetic flows with and without ORC unit reported in the following Table 3 shows that thanks to the complete heat use downstream the ORC unit the additional thermal power required from biomass is transformed almost completely into electricity.

	Base	CHP	Delta	% of delta furnace
Thermal power biomass furnace [MWth]	46,67	48,31	1,64	100%
Thermal power to dryer	20,00	20,00	0,00	0%
Thermal power to thermal oil users	20,00	20,00	0,00	0%
Pth lost in flue gases	6,67	6,67	0,00	0%
Pth lost in ORC	0,00	0,19	0,19	11%
PeI ORC	0,00	1,454	1,45	89%

Table 3 : Energy flow comparison of basic and CHP system based on an ORC unit

The assumptions' and results presented in this paragraph are based on the use of a fiber dryer without outlet air recirculation. If a scheme with partial recirculation of the flue gases at dryer outlet to dryer inlet is used a higher outlet temperature from the mixing chamber may be acceptable. This would lead to a lower flow of mixing air from ambient and therefore to a smaller size of the ORC unit for the same process heat request. Also the gas flow discharged to atmosphere would be lower leading to a higher thermal efficiency of the energy plant. The remaining conclusions of this chapter remain valid also with this plant configuration as shown by the example of MDF Hallein where a fiber dryer with flue gas recirculation is used.

3.3 Economic analysis of the CHP scheme with ORC unit

An "incremental" economical analysis of the additional investment in a CHP system was performed. In this analysis only the additional "incomes" and "costs" that result from the addition of an ORC system for cogeneration (that is to say only the incomes and the costs that would not exist if a heat-only system was implemented) are accounted for. In particular the following extra costs have been considered:

- Cost of the ORC module
- Extra costs for the additional thermal oil heater (including cost of the thermal oil circuit)

- Extra costs for hot water / air heat exchanger and related hot water circuit
- Extra costs for balance of plant
- Extra running costs due to the additional biomass consumption
- Extra costs for operation and maintenance of the ORC unit and additional thermal oil heater

The following extra income has been considered:

- Sale or avoided costs of the produced electricity (depending on the availability of a subsidized feed-in tariff)

In the following analysis the simple payback time of the additional investment for the cogeneration unit has been analyzed for biomass costs between 5 and 20 Euro/MWh and an electricity value between 60 and 160 Euro/MWh. The main assumptions are resumed as following :

Additional costs for cogeneration system : 3000 k€

Additional maintenance costs for cogeneration system :

30 k€ / year

Full load operation hours: 7600 hours/year

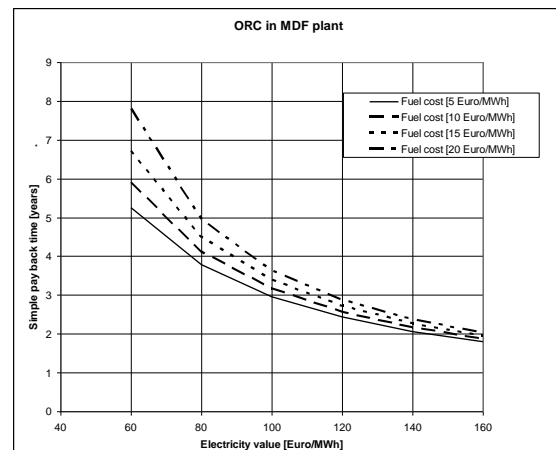


Figure 4 : Simple pay back time depending on electricity and fuel value

The data reported in Figure 4 show that the economical return of the investment are interesting also for conservative values of fuel and electricity value (simple PBT slightly above 4 years for an electricity value of 80 Euro/ MWh and fuel value of 10 Euro/ MWh) compatible with the market conditions in countries where no subsidized feed-in tariffs for renewable energy are available. In addition the analysis shows that also sensible variations of the fuel price have a comparatively low influence on the economical results. The results for higher values of electricity value compatible with the support schemes implemented in some European countries (Germany, Austria, Belgium, Italy, etc.) show excellent economical results with extremely low influence of the fuel value on the economical results (simple PBT between 2-3 years).

As the installation of the components necessary for the cogeneration section has almost no influence on the technical parameters of the remaining plant the considerations of this chapter can be considered to be

valid both for installation in a new plant and for installation in an existing plant.

Further applications of the ORC in this sector include cases where capacity increases are planned (as in the case MDF Hallein) and applications in cases where a higher than required thermal oil capacity is available. This last case is the most favorable as in this case the additional investment cost is almost exclusively limited to the ORC unit.

4 The case of MDF Hallein

MDF Hallein is a modern plant for the production of high quality MDF raw boards established in 1999 in the region of Salzburg, Austria. The company is part of the Binder group and is able to offer MDF raw boards for very different and specific applications in thicknesses from 3 to 30 mm. In the year 2001 a revamping of the system was planned with the main aim of increasing the production capacity to appr. 200.000 m³/year and in the following years with optimizations to 250.000 m³/year. The planned changes on the plant included mainly an increase of the press length to 34,7 m. This requested an increase in the combustion power of the energy plant. In Austria a fixed in feed-in tariff for renewable energy from biomass exists (electricity value about 16 Ec/kWh at the time of construction of the plant). Therefore the management of the company evaluated both the extension of the plant allowing the exclusive production of the additional heat required in order to reach the required additional drying capacity and different cogeneration schemes based both on steam turbine and the ORC unit. After evaluation a solution based on an additional thermal oil boiler and on a standard T1500 – CHP unit from Turboden was selected. The main reasons for the selection of this solution were :

- the high efficiency and reliability of the solution based on the ORC system
- the complete independence of the cogeneration system from the process scheme that allowed to have no influence on the reliability of the process caused by the cogeneration system.

This solution had also the advantage of extremely low operation and maintenance costs and limited additional costs compared to the heat only solution, leading to an optimal pay back of the additional investment. An interesting feature of the cogeneration plant in Hallein is also the fact that a part of the heat available from the condenser of the ORC unit is sold to the local district heating grid. This local heating grid is also connected with the much bigger grid of the city of Salzburg in order to assure a significant heat load also during summer.

4.1 Description of the energy plant and energy flows before the changes

The energy plant originally installed at MDF Hallein is equipped with a biomass furnace with a thermal capacity of 48 MW_{th}. Up to 26 MW_{th} were exchanged in the directly heated fiber dryers, up to 22 MW_{th} were transformed in the thermal oil heater. The energy balance

in nominal conditions is resumed in table 4.

	MW _{th}	%
Thermal power biomass furnace 1 (max. capacity)	48	100%
Thermal power in thermal oil heater 1 (Transformed to steam)	20,4 (15)	42,5%
Thermal power to dryer	25,2	52,5%
Thermal power discharged to ambient	2,4	5%

Table 4 : Energy balance of the original plant at MDF Hallein

4.2 Description of the energy plant and energy flows after the changes

During the revamping an additional furnace with a nominal combustion power of 12 MW_{th} and a new thermal oil heater with a nominal capacity of 10 MW_{th} and nominal thermal oil temperatures of 300/250°C (feeding / return) were installed. The flue gases of the new furnace appr. 2 MW_{th} are used in the existing dryers that were modified in order to be able to use the gases of both furnaces for fiber drying. For cogeneration a standard Turboden T1500 unit with nominal thermal oil input power of 9 MW_{th}, nominal net electric power of 1,5 MW_{el} and nominal heat supply to hot water of 7,2 MW_{th} was installed. The nominal hot water temperatures are 60/90°C (in /out), but operation up to 120°C is possible with a small decrease in thermodynamic efficiency. A thermal power of about 3 MW_{th} is used for preheating the mixing air for fiber drying. The remaining thermal power is supplied to the district heating grid depending on the request of the grid and for other local low temperature consumers. The system is controlled by the thermal power request of the process and of the district heating grid. If the low temperature heat request is lower than the thermal power available downstream the ORC unit in nominal conditions the new thermal oil furnace and the ORC unit are operated at partial load.

4.3 Economical considerations

The investment cost for the modifications in the existing energy plant including the modifications necessary anyway for supplying the additional heat to the production process and to the district heating grid amounted to about 5 M€. The additional costs for the cogeneration system, that means the difference between the total costs and the costs for a system supplying only the additional heat for drying and district heating, were evaluated to be about 3 M€. An electricity value of 160 Euro/MWh was considered together with the following values for the other main parameters of the differential feasibility study :

- Value of the additional fuel consumed : 20 Euro/ MWh
- Additional maintenance costs for cogeneration system : 30 k€ / year
- Full load operation hours: 6000 hours/year

With these assumptions a pay back time of the incremental cost in about 2,5 years is reached .

5 Conclusions

The Biomass cogeneration unit was started up at the end of November 2005 and has reached at the beginning of April 2007 11.000 operating hours corresponding to about 8100 hours of operation per year. The expected performances of the system have been continuously met or exceeded making this unit a perfect showcase of the possibility of application in fiberboard production plants. The continuous increase in the production capacity installed worldwide makes the market opportunities for further installation of ORC units in this sector very interesting.

6 References

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