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Spray enhanced demisting (SED)

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Abstract

A new innovative and efficient system has been studied, realized and tested by SWS's engineers for the production of top quality distillate TDS<0.1 ppm by evaporation of seawater in both MSF and MED desalination plants. This system is based on the combined effect of scrubbing the vapor outflowing from the demisters (with a spray of accelerated droplets of distillate) and of the mechanical coalescence in a further layer of demisters. The key factors of the main scrubbing process are the highest rate of hitting droplets velocity, the dimensions of the droplets and the number of droplets to be large enough to balance the statistically low impact efficiency. The arrangement of the system is very simple and has been protected by a patent since June 2001, registered by SWS. The benefits provided by this innovation are quite remarkable both for the dramatical reduction of the investment cost and for the high reliability of the plants whenever the fresh water product is requested for industrial services, such as make up to HP steam generators, and process water for the chemical industry being the suitable quality ensured without any further treatment of the distillate.

Keywords: Spray enhanced demister; Seawater evaporation; MSF; MED

1. Introduction

The purity of the fresh water product of seawater distillers is normally requested in the range of TDS content 2–10 ppm.

This content quite exceeds any actual requirement whenever the fresh water is produced for civil services (drinking or agricultural). When the fresh water is requested for industrial use, the final specification may need a much higher purity, such as TDS ≤ 0.1 ppm.

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The present status of the demisters technology allows for the reduction of the guaranteed TDS down to about 1 ppm or less (operating clean demisters) through the careful design of the vapor velocity and demisters' design.

This guaranteed TDS is not enough for the compliance with some services, such as make-up to HP boilers and feed to chemical process.

The common practice is the installation of polishing plants (ion exchange resins) for further treatment of the distillate up to the requested specification.

The train of two plants (distillation + polishing) presents a number of disadvantages, such as:

- high investment cost
- high running costs (mainly because of the regenerating chemicals for the resins)
- reduced reliability (operation regularity)
- double storage system for desalinated and polished water with dedicated volumes, pumps and automation.

2. Concept of the innovation

The studies completed by the SWS engineers were focused on the problem of quality of the distillate produced by distillation plants (MSF and MED) with the aim of ensuring TDS $\leq$ 0.1 ppm. The target includes a high degree of reliability where no further polishing would be any longer necessary to be installed to guarantee the purity of the product.

All the disadvantages listed in section 1 are accordingly overcome. Actually, the successful results achieved by the SWS engineers are now proven to match the target and to dramatically reduce both the total investment cost and the running and maintenance expenditures.

A number of different technologies have been considered since the very beginning of the preliminary studies for the treatment of vapor outflowing from the demisters and for the effective elimination of droplets of brine (mist) carried by the vapor into the condensation section of the desalinator.

From the analysis made in collaboration with the demisters specialists Messrs. Costacurta, Italy, it was found that the nature and the statistical distribution curve of the dimensions of the droplets are able to survive any high quality knitted mesh wire demister.

The dimension of these droplets was understood to be below 10 μ in diameter, with a peak of mass concentration in the range of 5–8 μ in diameter.

The analysis of the concentration shows a TDS slightly lower than that of the originating brine, i.e. usually in the range of 55,000 to 70,000 ppm according to the criteria of the desalination design. The TDS content of the distillate is entirely due to the total mass flow of these droplets carried by the vapor through the demisters up to the condensation. Considering the average purity of the distillate as 2 ppm, the brine mass carried by the vapor is in the range of 1/30,000, consisting of droplets as described above. We may consider that each ton of steam carries approximately 30 g of brine consisting of 250 billion of overage droplets. The possibility of achieving an effective bi-phase separation in this stage was the focus of the studies of the SWS engineers. After the deeper technical consideration and laboratory tests, the following processes were abandoned because they were not unfeasible for industrial application at real desalination plants:

(a) Electrical coalescence, to be achieved by flowing the vapor impact of the brine droplets (by bipolarity attraction) and the modification of the overage droplets dimension for the improved demisting efficiency (by the reduction of the number of the small droplets).

(b) Ultrasonic coalescence

(c) The preferred process selected for industrial implementation was a combination of mechanical scrubbing and mechanical coalescence, achieved through the impact of the brine droplets with a suitable number of quick drops of distillate properly spayed into the vapor flow.

The development of the studies and the construction of the prototype were all in accordance with option (c) above that requires a very simple and safe mechanical arrangement. This system is called SED (Spray Enhanced Demisting).

3. Theoretical approach

3.1. The SED system works according to the principles of the scrubbing. The droplets of brine carried by the up flowing vapor as mist, are hit by scrubbing drops of sprayed pure water (part of the distillate). Upon a proper efficiency of the scrubbing, the original droplets of brine (survived from the lower demister — section 2.1) are replaced by new drops originated by the mechanical coalescence with the scrubbing drops, and the final salinity is calculated according to section1.2.

3.2. By the experiences of demister application, the brine droplets surviving the demisters are deemed to be:

Ø<10 μ (average 7.5 μ)

Q < 0.005% of the vapor weight

V upflowing <12 m/s at maximum vacuum conditions

V_s setting ≅0.5 m/s at maximum vacuum conditions

3.3. The key issue for the effectiveness of the scrubbing is the efficiency of the impact. Only a small portion of the sprayed hitting drops is effectively impacting the brine droplets.

The efficiency of impact is calculated as follows:

$$e = \frac{V_R}{D} \cdot \frac{V_S}{g} \tag{1}$$

where V_R is the velocity of hitting drops, m/s; V_S velocity of setting of brine droplets, m/s; D dimension of hitting drops, μ; g acceleration of gravity.

3.4. The SED sprayers are to be designed properly for achieving the necessary efficiency. Considering sprayed drops: Ø = 15 μ, V_R = 20 m/s and V_S = 0.5 m/s, the efficiency (section3.3) is:

$$e = \frac{20}{15} \cdot \frac{0.5}{9.8} = 6.7\% \tag{2}$$

This means that the flow of sprayed water has to be ~15 times the quantity calculated for the full geometrical coverage of the vapor up flowing section. Any efficiency exceeding 5% is to be considered excellent in this respect.

3.5. For each m^2 of vapor section (demister area), the full coverage of the area is ensured by the flow of:

$$Q = \frac{Ø \cdot 1}{V_R} = \frac{0.015}{20} = 7.5 \cdot 10^{-4} \text{ kg/s} \tag{3}$$

Considering the drops (section 3.4) and the requested efficiency e = 6.7%, 15 times this flow is 0.0112 kg/s = 40 kg/h. The flow of water to be sprayed in the conditions of section 3.4, is therefore 40 kg/h, 6.7% of it being effective, for each m^2 of demisters' area. Considering the typical production of 1 m^2 of demister area = 2000 kg/h, the sprayer's duty is ~2% of the production rate.

3.6. The typical calculation of section3.5 is to be specifically made for each project, considering the actual design parameters.

3.7. The coalesced water composition, after impact with the drops, shall be resulting from the mix of:

- The entirety of brine droplets (section 3.2)
- 6.7% of the sprayed water

The expected typical salinity of the new coalesced droplets is accordingly:

$$\frac{0.005 \cdot 50{,}000 + 2 \cdot 0.067 \cdot 2}{0.005 + 2} = 125 \text{ ppm} \tag{4}$$

These droplets replace the original ones with over 50,000 ppm. The droplets approaching the upper demister (section 2.3) shall bear an average salinity 400 times lower than the original brine.

3.8. The expected salinity of the vapor which flowed through the upper demister is to be 1/400 of the vapor flown through the lower demister (typically TDS = 2 ppm). The target of the SED system however is to reduce the salinity 20 times from 2 ppm to 0.1 ppm as requested by the most severe services.

3.9. The available safety factor 1:20 (as calculated in section 3.8.) is found to be sufficient for balancing a number of approximations made in theoretical study, as follows:

- The range of dimensions of the sprayed drops is actually quite wide, and a remarkable ratio of sprayed drops are larger than nominal, with a decrease in the predicted efficiency (section 3.3).
- The range of velocity of the sprayed drops is actually quite wide, and a remarkable ratio of sprayed drops have lower velocity than nominal, with a decrease in the predicted efficiency (section 3.3).
- The layout arrangement of the nozzles (in spite of the mechanical optimization) cannot ensure the really uniform density of the drops in the SED area, and accordingly some preferential paths are present with less intensive spray effect.

3.10. The evaluation of the requested safety factor (section 3.9) is to be made specifically for each project (section 3.6) for the reliable prediction of the vapor final quality and for the relevant performance guarantees.

4. Prototype — construction and tests

After the completion of the preliminary studies, a prototype of SED was decided to be constructed for the actual operation test, for the following installation in a real commercial plant.

The most appropriate case for the installation of the SED equipment was the MED unit awarded to SWS by Hyundai in 2000, on behalf of the J.V. Snamprogetti-Hyundai, for the production of the fresh water requested by QGPC in NGL-4 project (Qatar).

The reason is mostly due to the small size of the unit — 50 m^3/d, and because of the quick time of delivery and of the procedures agreed for the site assistance of SWS in commissioning and start-up.

Although the contractually guaranteed fresh water purity is 5 ppm, the SED system was installed as an additional unpaid option, arranged so that it can be operated whenever decided, just by turning a manual 3/4″ valve.

Some 5% over design was included in the project for ensuring 100% production rate even in the case of SED operating mode. Accordingly, QGPC is enjoying the possibility of either producing 100% at 0.1 ppm purity or producing 105% at 5 ppm purity (actually TDS of 1 ppm is achieved even in the case of excluded SED mode as the result of two demisters installed in sequence).

Remark: The operation tests are now being completed, and full reports will be available in a very near future. The SED prototype consists of the following equipment, besides the 5% over sizing of the plant (corresponding to the total reduction of the production efficiency):

- N. 1 on-off valve for the operation/exclusion of the system, located in the pressure line coming from the head of the distillate extraction pumps.
- N. 2 distillate-spraying headers, each bearing N. 5 spraying nozzles. The design of the nozzles was specifically reviewed by SWS engineers in cooperation with the manufacturer. By these nozzles, the requested high-energy flat cone is ensured.

Each sprayer in SS 316 L ensures the following performance:

F = 5 l/h at ΔP = 3.5 bar
Droplet size 10–25 μ
Droplet velocity 15–20 m/s

Laboratory tests were satisfactorily assessed before the validation of the nozzles design.

Fig. 1.

Fig. 2.

Fig. 3.

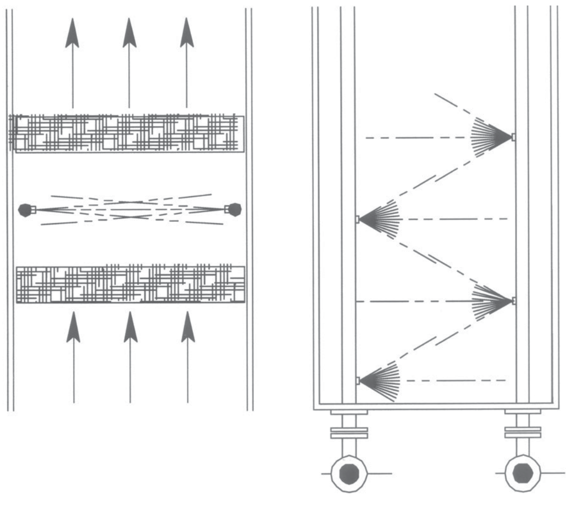

Fig. 4. SED system installation scheme.

- N. 2 demisters layers, each one according to the standard design of Messrs. Costacurta, specifically selected by SWS engineers.

  Style knitted wire mesh 316 L
  Vacuum 97%
  Height 100 mm

No distillate heater was installed, and accordingly in this specific application the SED will not enjoy the additional efficiency provided by the partial flash of the distillate while being sprayed, after heating.

The distillate is sprayed at its extraction temperature of approximately 43°C (before distillate cooler).

5. Conclusion

- The SED system is now successfully tested and ready for commercial application. Its cost is proven to be dramatically lower than any polishing plant to be installed for further treatment of the distillate, whenever the requested purity exceeds 1 ppm. The reliability of the SED system is based on its mechanical simplicity and by far exceeds the reliability of any resin treatment plant.

- The environmental impact of the SED system is much more favorable than any resin treatment system, since the resin requirs the consumption and disposal of the regenerating chemicals.
- The SED system is protected by the patent registered by SWS, but will be anyway available to any supplier of desalination plants, upon a fair cooperation agreement.
- The SED system is applicable to both MED and MSF desalination units. Partial application on single stages/effects is possible and recommended whenever the combined service is to be provided for industrial end civil utilization. In this case a separate extraction of the distillate produced in the SED equipped stages/effects, is to be ensured by adequate additional pumps.
- The SED is also applicable in most of the cases to the existing plants, providing that the geometry of the stages/effects is suitable for the installation of the additional demister.

The engineers of SWS are available for any survey and for any review of drawings, and accordingly confirm the possibility of installation, as well as determine the ensured purity of the fresh water and the reduction of the total maximum production rates of the plant.