SUMMARY

In one aspect, there is provided a system (3) for controlling an argon flow rate of a fluid (120) at an outlet of an assembly (1) of at least one distillation column in order to achieve a target dioxygen content (SP), the system comprising: a sensor (9) designed to measure a dioxygen content (PV) in a fluid comprising argon at the outlet of the assembly of at least one distillation column; a regulator (11) designed to determine a required argon flow rate variation (Δ_{regul}) depending on the difference (ε) between the dioxygen content measured by the sensor and the target dioxygen content; a controller (13) designed to generate a control signal relating to a target argon flow rate (Q_{argon}), said target argon flow rate being determined depending on the required argon flow rate variation determined by the regulator and on variations in the dioxygen content measured by the sensor; and a valve (15) controlled by said controller and designed to modify the argon flow rate of the fluid at the outlet of the assembly of at least one distillation column in order to obtain the target argon flow rate; wherein the target argon flow rate determined by the controller being determined additionally depending on a predictive value (Q_{pred}) of the argon flow rate depending on an air flow rate (Q_{air}) at an inlet of the assembly of at least one distillation column and on a yield (ρ) of said assembly; and wherein the predictive value of the argon flow rate depends on an air flow rate (Q^*_{air}) which is delayed relative to the air flow rate at the inlet of the assembly (1) of at least one distillation column, said delayed air flow rate being defined as follows:

$$Q^*_{air}(t) = Q_{air}(t) \text{ while } Q_{air}(t) - Q_{air}(t-\delta) < R$$
$$\text{if, at } t = t_0, R \leq Q_{air}(t_0) - Q_{air}(t_0 - \delta), \text{ then:}$$
$$Q^*_{air}(t) = Q_{air}(t_0 - \lambda) \text{for all } t \in [t_0; t_0 + \lambda]$$

where:

- $Q^*_{air}(t)$ is the delayed flow rate at time t,
- $Q_{air}(t)$ is the air flow rate at the inlet of the assembly of at least one distillation column at time t,
- t_0 is any time,
- λ and δ are predetermined periods of time,
- R is a predetermined positive threshold.

In another aspect, there is provided process for controlling an argon flow rate of a fluid (120) at an outlet of an assembly (1) of at least one distillation column in order to achieve a target

dioxygen content (SP), the process comprising: measuring a dioxygen content (PV) in a fluid comprising argon at the outlet of the assembly of at least one distillation column, determining a required argon flow rate variation (Δ_{argon}) depending on the difference (ε) between the measured dioxygen content and the target dioxygen content, determining, depending on the required argon flow rate variation and on variations in the measured dioxygen content, a target argon flow rate (Q_{argon}), and modifying the argon flow rate of the fluid at the outlet of the assembly of at least one distillation column in order to obtain the target argon flow rate; wherein the target argon flow rate is determined additionally depending on a predictive value (Q_{pred}) of the argon flow rate depending on an air flow rate (Q_{air}) at an inlet of the assembly of at least one distillation column and on a yield (ρ) of said assembly; and wherein the predictive value of the argon flow rate depends on an air flow rate (Q^*_{air}) which is delayed relative to the air flow rate at the inlet of the assembly (1) of at least one distillation column, said delayed air flow rate being defined as follows:

$$Q^*_{air}(t) = Q_{air}(t) \text{ while } Q_{air}(t) - Q_{air}(t-\delta) < R$$
$$\text{if, at } t = t_0, R \leq Q_{air}(t_0) - Q_{air}(t_0 - \delta), \text{ then:}$$
$$Q^*_{air}(t) = Q_{air}(t_0 - \lambda) \text{for all } t \in [t_0; t_0 + \lambda]$$

where:

- $Q^*_{air}(t)$ is the delayed flow rate at time t,
- $Q_{air}(t)$ is the air flow rate at the inlet of the assembly of at least one distillation column at time t,
- t_0 is any time,
- λ and δ are predetermined periods of time,
- R is a predetermined positive threshold.

DETAILED DESCRIPTION

The invention concerned here relates to a system for controlling an argon flow rate of a fluid at the outlet of an assembly of at least one distillation column in order to achieve a target dioxygen content. The system comprises:

- a sensor designed to measure a dioxygen content in a fluid comprising argon at the outlet of the assembly of at least one distillation column,

- a regulator designed to determine a required argon flow rate variation depending on the difference between the dioxygen content measured by the sensor and a target dioxygen content,

- a controller designed to generate a control signal relating to a target argon flow rate, said target argon flow rate being determined depending on the required argon flow rate variation determined by the regulator and on variations in the dioxygen content measured by the sensor, and

- a valve controlled by said controller and designed to modify the argon flow rate of the fluid at the outlet of the assembly of at least one distillation column in order to obtain the target argon flow rate.

The variations of the flow rate of the fluid comprising argon at the outlet of the assembly of at least one distillation column in fact have a direct impact on the dioxygen content of this fluid. Thus, the system described here determines an argon flow rate, that is to say the target argon flow rate, for achieving the target dioxygen content.

In one or more embodiments, the assembly of at least one distillation column is supplied with an air fluid, the target argon flow rate determined by the controller being determined additionally depending on a predictive value of the argon flow rate depending on the air flow rate at the inlet of the assembly of at least one distillation column and on a yield of said assembly.

According to one aspect of the invention, the predictive value of the argon flow rate depends on an air flow rate which is delayed relative to the air flow rate at the inlet of the assembly of at least one distillation column, said delayed air being defined as follows:

$$\mathrm{Q^{*}_{air}(t) = Q_{air}(t)}\ \textit{while}\ \mathrm{Q_{air}(t) - Q_{air}(t-\delta)} < R$$
$$\text{if, at } \mathrm{t} = t_0, \mathrm{R} \leq \mathrm{Q_{air}(t_0) - Q_{air}(t_0 - \delta)}, \text{then:}$$

$$Q^*_{air}(t) = Q_{air}(t_0 - \lambda) \text{for all } t \in [t_0; t_0 + \lambda[$$

where:

- $Q^*_{air}(t)$ is the delayed flow rate at time t,
- $Q_{air}(t)$ is the air flow rate at the inlet of the assembly of at least one distillation column at time t,
- t_0 is any time,
- λ and δ are predetermined periods of time,
- R is a predetermined positive threshold.

According to another aspect of the invention, the predictive value of the argon flow rate at a given time is determined as follows:

$$Q_{pred}(t) = Q^*_{air}(t) \times \alpha \times \rho$$

where:

- $Q_{pred}(t)$ is the predictive value of the argon flow rate at a given time *t*,
- α is the proportion of argon in the air flow at the inlet of the assembly of at least one distillation column,
- ρ is the yield of the assembly of at least one distillation column.

According to another aspect of the invention, the yield of the assembly of at least one distillation column is determined by applying a predetermined function to a factor characterizing an amount of energy used for operating the assembly of at least one distillation column.

According to another aspect of the invention, the predetermined function is determined by a learning algorithm on the basis of a set of data relating to a plurality of distillation processes implemented according to different values for the amount of energy used.

According to another aspect of the invention, the predetermined function is polynomial.

$$\Delta_{regul}(p) = [G_p \times p + \frac{G_i}{p} + G_d \times p^2] \times \varepsilon(p)$$

It is known in addition that the determination of the output of a PID controller may include other operations in addition to the determination of the proportional, integral and derivative responses.

Advantageously, the regulator 11 is configured so that the values of the parameters G_p and G_i respectively relating to the proportional and integral contributions of the regulator 11 are multiplied by two when the dioxygen content PV measured by the sensor 9 is greater than the target dioxygen content SP. In other words, by adopting the notations G_p^+ and G_i^+ in the case where the measured dioxygen content PV is greater than the target dioxygen content SP, and the notations G_p^- and G_i^- in the case where the measured dioxygen content PV is less than the target dioxygen content SP, the following is obtained:

$$G_p^+ = 2 \times G_p^-$$

$$G_i^{-+} = 2 \times G_i^-$$

According to one embodiment, the regulator 11 is a PI ("*proportional-integral*") controller. In other words, in this embodiment, the regulator 11 is designed to determine a proportional response and an integral response to the difference ε between the measured dioxygen content PV and the target dioxygen content SP. Another way to conceive of this embodiment is to consider that the regulator 11 is a PID controller with a derivative response of zero. In other words:

$$G_d = 0$$

Of course, those skilled in the art will understand that it is equivalent and just as relevant to measure the SP-PV difference instead of the PV-SP difference.

As illustrated in **figure 1** and in **figure 4**, the regulator 11 includes a memory ~~25~~ 21 and a processor ~~27~~23.

The memory ~~25~~ 21 is designed to store instructions which when executed by the processor ~~27~~ 23 result in the operation of the regulator 11.

The controller 13 is designed to receive the required argon flow rate variation Δ_{regul} determined by the regulator 11. Furthermore, as explained above, the controller 13 is also coupled to the

From t = 140 min, the actual air flow rate Q_{air} continues to increase, but with a shallow slope this time, until t = 200 min. Specifically, over this interval of time delimited by the points B and ~~C~~ D on the curve illustrated in **figure 2**, the actual air flow rate Q_{air} increases by approximately 0.42 m^3/h each minute, which is therefore less than the predetermined threshold R = 1 m^3/h. When the slope is shallow, the delayed flow rate Q^*_{air} is therefore equal to Q_{air}, but only when the period of time of 40 minutes, still in progress at t = 140 min, during which the value of the delayed flow rate $Q^*_{air}(t)$ is held constant, ends, that is to say at t = 160 min.

Finally, on the portion of the curve delimited by the points D and E, the curve of the actual air flow rate Q_{air} is decreasing and the variation in the actual air flow rate Q_{air} over 1 minute remains below the predetermined threshold R = 1 m^3/h. The delayed air flow rate Q^*_{air} is therefore equal to Q_{air} between t = 200 min and t = 280 min.

During step S3, therefore, the delayed air flow rate value $Q^*_{air}(t)$ at time t is determined. This values is for example determined by the controller 13 which thus receives, in this embodiment, the measurement of the air flow rate Q_{air} at the inlet of the assembly 1 of at least one distillation column. Alternatively, the value of the delayed air $Q^*_{air}(t)$ is transmitted directly to the controller 13.

During a step S4, the controller 13 determines the predictive value $Q_{pred}(t)$ of the argon flow rate depending on the air flow rate Q_{air} at the inlet of the assembly 1 of at least one distillation column and on a yield of the assembly 1. According to one embodiment, the predictive value $Q_{pred}(t)$ is more precisely determined depending not on the air flow rate Q_{air} at the inlet of the assembly 1, but on the delayed air flow rate Q^*_{air} and on the yield of the assembly 1.

For example, for a given time t, the predictive value $Q_{pred}(t)$ of the argon flow rate is determined by the controller 13 as follows:

$$Q_{pred}(t) = Q^*_{air}(t) \times \alpha \times \rho$$

where:

- $Q_{pred}(t)$ is the predictive value of the argon flow rate at a given time *t*,
- α is the proportion of argon in the air flow at the inlet of the assembly of at least one distillation column,
- ρ is the yield of the assembly of at least one distillation column.

Claims

1. A system (3) for controlling an argon flow rate of a fluid (120) at ~~the~~ an outlet of an assembly (1) of at least one distillation column in order to achieve a target dioxygen content (SP), the system comprising:

   - a sensor (9) designed to measure a dioxygen content (PV) in a fluid comprising argon at the outlet of the assembly of at least one distillation column,

   - a regulator (11) designed to determine a required argon flow rate variation (Δ_{regul}) depending on the difference (ε) between the dioxygen content measured by the sensor and ~~a~~ the target dioxygen content,

   - a controller (13) designed to generate a control signal relating to a target argon flow rate (Q_{argon}), said target argon flow rate being determined depending on the required argon flow rate variation determined by the regulator and on variations in the dioxygen content measured by the sensor, and

   - a valve (15) controlled by said controller and designed to modify the argon flow rate of the fluid at the outlet of the assembly of at least one distillation column in order to obtain the target argon flow rate~~.~~;

   - wherein the target argon flow rate determined by the controller being determined additionally depending on a predictive value (Q_{pred}) of the argon flow rate depending on an air flow rate (Q_{air}) at an inlet of the assembly of at least one distillation column and on a yield (ρ) of said assembly; and

   wherein the predictive value of the argon flow rate depends on an air flow rate (Q^*_{air}) which is delayed relative to the air flow rate at the inlet of the assembly (1) of at least one distillation column, said delayed air flow rate being defined as follows:

$$Q^*_{air}(t) = Q_{air}(t) \text{ while } Q_{air}(t) - Q_{air}(t-\delta) < R$$
$$\text{if, at } t = t_0, R \leq Q_{air}(t_0) - Q_{air}(t_0 - \delta), \text{ then:}$$
$$Q^*_{air}(t) = Q_{air}(t_0 - \lambda) \text{for all } t \in [t_0; t_0 + \lambda]$$

where:

- $Q^*_{air}(t)$ is the delayed flow rate at time t,
- $Q_{air}(t)$ is the air flow rate at the inlet of the assembly of at least one distillation column at time t,
- t_0 is any time,
- λ and δ are predetermined periods of time,
- R is a predetermined positive threshold.

2. The system as claimed in claim 1, wherein the assembly of at least one distillation column is supplied with an air fluid (100)~~, the target argon flow rate determined by the controller being determined additionally depending on a predictive value (Q_{pred}) of the argon flow rate depending on the air flow rate (Q_{air}) at the inlet of the assembly of at least one distillation column and on a yield (ρ) of said assembly~~.

~~3. The system as claimed in claim 2, wherein the predictive value of the argon flow rate depends on an air flow rate (Q^*_{air}) which is delayed relative to the air flow rate at the inlet of the assembly (1) of at least one distillation column, said delayed air flow rate being defined as follows:~~

$$Q^*_{air}(t) = Q_{air}(t) \text{ while } Q_{air}(t) - Q_{air}(t-\delta) < R$$
$$\text{if, at } t = t_0, R \leq Q_{air}(t_0) - Q_{air}(t_0 - \delta), \text{ then:}$$
$$Q^*_{air}(t) = Q_{air}(t_0 - \lambda) \text{ for all } t \in [t_0; t_0 + \lambda[$$

~~where:~~

- ~~$Q^*_{air}(t)$ is the delayed flow rate at time t,~~
- ~~$Q_{air}(t)$ is the air flow rate at the inlet of the assembly of at least one distillation column at time t,~~
- ~~t_0 is any time,~~

- ~~λ and δ are predetermined periods of time,~~
- ~~R is a predetermined positive threshold.~~

~~4~~3. The system as claimed in claim ~~3~~1, wherein the predictive value of the argon flow rate at a given time is determined as follows:

$$Q_{pred}(t) = Q^{*}_{air}(t) \times \alpha \times \rho$$

where:

- $Q_{pred}(t)$ is the predictive value of the argon flow rate at a given time *t*,
- α is the proportion of argon in the air flow at the inlet of the assembly of at least one distillation column,
- ρ is the yield of the assembly of at least one distillation column.

~~5~~4. The system as claimed in any of claims 2 to ~~4~~3, wherein the yield of the assembly of at least one distillation column is determined by applying a predetermined function to a factor characterizing an amount of energy used for operating the assembly of at least one distillation column.

~~6~~5. The system as claimed in claim ~~5~~4, wherein the predetermined function is determined by a learning algorithm on the basis of a set of data relating to a plurality of distillation processes implemented according to different values for the amount of energy used.

~~7~~6. The system as claimed in claim ~~6~~5, wherein the predetermined function is polynomial.

~~8~~7. The system as claimed in one of the preceding claims, wherein the target argon flow rate is determined depending on an anticipation parameter (P) relating to the variations

in the dioxygen content measured by the sensor, said anticipation parameter taking discrete values within a set of predetermined values.

~~9~~8. The system as claimed in claim ~~8~~7, wherein the anticipation parameter relating to the variations in the dioxygen content is defined as follows:

$$P(t) = \begin{cases} P_1 \text{ if } |PV(t) - PV(t-\tau)| \leq S \\ P_2 \text{ if } PV(t) - PV(t-\tau) > S \\ P_3 \text{ if } PV(t) - PV(t-\tau) < -S \end{cases}$$

where:

- P(t) is the value of the anticipation parameter relating to the variations in the dioxygen content measured by the sensor at time t,
- P_1, P_2, P_3 are possible values of the anticipation parameter according to the variations in the dioxygen content measured by the sensor,
- PV(t) is the value of the dioxygen content measured by the sensor at time t,
- τ is a predetermined period of time, and
- S is a predetermined threshold.

~~10~~9. The system as claimed in claim ~~9~~ 8 taken in combination with claim 2, wherein the anticipation parameter relating to the variations in the dioxygen content measured by the sensor is a corrective flow rate, the target argon flow rate being determined as follows:

$$Q_{argon} = Q_{pred} + \Delta_{regul} + P$$

where:

- Q_{argon} is the target argon flow rate,
- Q_{pred} is the predictive value of the argon flow rate,
- Δ_{regul} is a required argon flow rate variation, and

- P is the value of the corrective flow rate.

~~11~~10. The system as claimed in claim ~~9~~ 8 taken in combination with claim 2, wherein the anticipation parameter relating to the variations in the dioxygen content measured by the sensor is a weighting coefficient of the predictive value of the argon flow rate, the target argon flow rate being determined as follows:

$$Q_{argon} = Q_{pred} \times P + \Delta_{regul}$$

where:

- Q_{argon} is the target argon flow rate,
- Q_{pred} is the predictive value of the argon flow rate,
- Δ_{regul} is a required argon flow rate variation, and
- P is the value of the weighting coefficient of the predictive value of the argon flow rate.

~~12~~11. The system as claimed in one of claims ~~2~~ 1 to ~~11~~10, wherein the argon flow rate predictive value is weighted by a corrective factor (K) relating to disturbances of the assembly of at least one distillation column, said corrective factor being determined depending on the difference between the dioxygen content measured by the sensor and the target dioxygen content.

~~13~~12. The system as claimed in claim ~~12~~11, wherein the corrective factor is defined as follows:

$$K = \begin{cases} K_1 \text{if } PV(t) - SP \geq T_1 \\ K_2 \text{ if } T_2 < PV(t) - SP < T_1 \\ K_3 \text{ if } PV(t) - SP \leq T_2 \end{cases}$$

where:

- K_1, K_2 and K_3 are predetermined possible values of the corrective factor, and

- T_1 and T_2 are predetermined thresholds.

~~14~~13. The system as claimed in one of the preceding claims, wherein the regulator is a PID ("*proportional-integral-derivative*") controller configured such that the values of the parameters respectively relating to the proportional and integral contributions of the PID controller are multiplied by two when the dioxygen content measured by the sensor is greater than the target dioxygen content.

~~15~~14. The system as claimed in claim ~~14~~13, wherein the PID controller is a PI controller.

~~16~~15. The system as claimed in one of the preceding claims, wherein the target dioxygen content of the argon fluid at the outlet of the assembly of at least one distillation column is less than 2 ppm.

~~17~~16. The system as claimed in claim ~~16~~15, wherein the target dioxygen content of the argon fluid at the outlet of the assembly of at least one distillation column is between 0.9 ppm and 2 ppm.

~~18~~17. The system as claimed in claim ~~16~~ 15 or ~~17~~16, wherein the target dioxygen content of the argon fluid at the outlet of the assembly of at least one distillation column is equal to 0.9 ppm.

~~19~~18. A process for controlling an argon flow rate of a fluid (120) at ~~the~~ an outlet of an assembly (1) of at least one distillation column in order to achieve a target dioxygen content (SP), the process comprising:

- measuring a dioxygen content (PV) in a fluid comprising argon at the outlet of the assembly of at least one distillation column,

- determining a required argon flow rate variation (Δ_{argon}) depending on the difference (ε) between the measured dioxygen content and ~~a~~ the target dioxygen content,

- determining, depending on the required argon flow rate variation and on variations in the measured dioxygen content, a target argon flow rate (Q_{argon}), and

- modifying the argon flow rate of the fluid at the outlet of the assembly of at least one distillation column in order to obtain the target argon flow rate;

- wherein the target argon flow rate is determined additionally depending on a predictive value (Q_{pred}) of the argon flow rate depending on an air flow rate (Q_{air}) at an inlet of the assembly of at least one distillation column and on a yield (ρ) of said assembly; and

wherein the predictive value of the argon flow rate depends on an air flow rate (Q^*_{air}) which is delayed relative to the air flow rate at the inlet of the assembly (1) of at least one distillation column, said delayed air flow rate being defined as follows:

$$Q^*_{air}(t) = Q_{air}(t) \text{ while } Q_{air}(t) - Q_{air}(t-\delta) < R$$
$$\text{if, at } t = t_0, R \leq Q_{air}(t_0) - Q_{air}(t_0 - \delta), \text{ then:}$$
$$Q^*_{air}(t) = Q_{air}(t_0 - \lambda) \text{ for all } t \in [t_0; t_0 + \lambda]$$

where:

- $Q^*_{air}(t)$ is the delayed flow rate at time t,
- $Q_{air}(t)$ is the air flow rate at the inlet of the assembly of at least one distillation column at time t,
- t_0 is any time,
- λ and δ are predetermined periods of time,
- R is a predetermined positive threshold.

~~20~~19. A computer program comprising instructions for implementing the process as claimed in claim ~~19~~ 18 when said instructions are executed by at least one processor (19,