APC of LOR Debutanizers makes use of inferential predictions

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Following good experience with the GCC (generalized cut-point calculation) inferential package, which models main fractionators with side-streams, TOTAL has decided to experiment with the GDS (generalized distillation shortcut) inferential package, which models simpler, two-product distillation columns. Several GDS models have been implemented at Lindsey Oil Refinery (LOR) and this paper focuses on two debutanizers: FCC gas plant debutanizer and Unifiner debutanizer. Precise separation of FCC LPG from naphtha is of value because olefinic FCC butane is an alkylation ingredient, whereas pentane is a MoGas component. Pentane being sent to the alkylation unit takes capacity and makes undesirable reactions. As for the unifiner, separation of LPG from LSR (light straight run naphtha) is of value because LSR is a MoGas component, and high RVP makes it difficult to blend.

GCC discussion.

Before going into the GDS discussion we would like to briefly describe the GCC model and extent of utilization at TOTAL. GCC applies heat balance, mass balance and partial pressure corrected temperatures to estimate the crude TBP (true boiling point) curve. Then from TBP and internal reflux, GCC proceeds to estimate product properties. Not only is GCC good at providing inference model but also these models are robust enough to remain in closed loop control during crude switches, indeed we would consider that is quite an advantage.

Total has implemented successfully GCC on multiple crude distillation units across the organization and in particular at LOR. Figure 1 is one example out of many, demonstrating GCC inferential performance for several days at LOR crude unit 2. This chart trends 10 days of selected GCC inferences (blue) versus lab (magenta squares). The red line at the bottom of figure 1 is a trend of the slope of crude TBP curve. IE, the increase in temperature needed to increase evaporation by 1% of the crude being run at the moment. During the ten-day period there were two massive crude switches, first going from intermediate to heavy, then returning to intermediate. On day nine there was another switch, not as massive. In addition there were several minor switches, probably tank-to-tank switches of the same crude. During the period inferred properties were trending well against the lab and APC continued uninterrupted.
There are many papers documenting the GCC technology and related APC performance, see for example [1, 2, 3, 4, 5]

GDS theory

While GCC makes use of boiling curves without defined composition, GDS works with distinct components, and analyzes DCS measurements around a specific section of a distillation column to come up with an inferential model. The green area of figure 2 shows measurements around the lower part of a stripping section. The inputs are pressure, certain temperatures plus enough measurements to permit vapor and liquid traffic calculation by heat balance. A minimum of two column temperature points are needed, one at the bottom and the other on a tray, distant enough from the bottom to have a light key component content of 10% or above.

The model makes use of Colburn's method [12], which estimates the ratio of vapor composition on tray N (the upper temperature measurement tray) to bottom liquid composition. It is a convenient closed form calculation, which correctly takes into account nonlinear effects of column loading and number of trays. For a simple stripping section Colburn ratio takes the following form

Ri = 1 + (Zi-1) * (Ki-1) / (Ui-1)
Ri = Ytrayi / Xboti (The Colburn ratio)
Ki = Component i volatility (vapor to liquid composition)
(V/L) = vapor to liquid molar flow ratio (calculated by heat balance)
Ui = Ki * (V/L) That is the effect of column loading
N = number of theoretical trays in section
Zi = Ui ^ N

Following calculation of volatilities, column loading and Colburn ratios GDS simplifies the composition into four components and it solves a set of four equations with four unknowns. Following is a GDS equation set for a debutanizer stripping section. The problem set-up has four unknowns to describe column bottom composition: NC4, C5, C6, C7+.

- NC4 is the light key component, to be kept at a level of 0.5 – 1%
- C5 is the heavy key component, volatile on all stripping trays
- C6 is so called heavy-heavy key component, volatile in lower trays only
- C7+ is extra-heavy key, assumed nonvolatile even inside the reboiler

To estimate the bottom composition GDS comes up with four equations. In it's simplest form the four equations are -

- Equation 1. Bottom mass balance
  Σ (Xboti) = 1
  (Sum of bottom molar fractions = 1)

- Equation 2. Reboiler equilibrium
  Σ (Kboti * Xboti) = 1
  (□um of reboiler vapor molar fraction = 1, that indicates equilibrium)

- Equation 3. Section separation
  Σ (Ri * Xboti) = 1
  (□um of tray N vapor molar fraction = 1)
  Ri is the Colburn ratio [5] for component i, the ratio between vapor composition on tray N to bottom liquid composition.

- Equation 4. Tray equilibrium
  Σ [(Ri / Ktrayi) * Xboti] = 1
  (□um of tray N liquid molar fraction = 1)
  (1 / Ktrayi) is the ratio of vapor to bottom liquid composition on tray N. Hence equation 4 is a tray equilibrium equation.

While the four by four matrix coefficient calculations are nonlinear and involved, the four resulting equations above are linear and solution is guaranteed. The calibration procedure for this model involves adjusting tray efficiency for the total section and for tray N (affecting equation 4), to obtain a good fit between model and lab results.

FCC debutanizer description

Consider the debutanizer of figure 3, column C-4. Tray temperature controller (TC) manipulates the reboiler whereas operators or APC manipulate reflux flow. Distillation control is a two by two problem, the two degrees of freedom being “cut” and “fractionation”. “Cut” is distillate yield to be manipulated when one product is too pure, the other too contaminated. “Fractionation” is column loading, to be manipulated when both products are too pure or too contaminated. Debutanizer tray TC is a cut control device. When the tray is too cold the TC increases reboiling, sending more vapor to the overhead drum and eventually to the distillate, increasing the cut. It helps that tray temperature is also a rudimentary inference of product purity. Such a control structure is convenient because it avoids interactions between cut and fractionation. Changes of cut do not alter the reflux. Changes of reflux and column loading have some dynamic effect but do not alter the steady state tray temperature, and only minimally alter the cut.

Debutanizer pressure is controlled by manipulation of gas flow to condensers, a method commonly used with fully condensed overhead product. The hot bypass shown is always shut though.

DCS overhead drum level control is on the LPG product, except here, due to downstream unit issues LPG flow can be manipulated only slowly and up to a certain limit. Hence when APC is active, it takes over level control and if necessary sacrificing distillation purity economics. At time when there are no constraints economics call for maximizing the content of C5 in butane up to about 1%. GDS actually infers C5 in LPG, but it also calculates the complete LPG composition: C2, C3, C4 and C5, and hence can estimate C5 impurity in total butane, two columns downstream of the debutanizer.

FCC debutanizer inferences

Figure 4 trends the content of C5 in butane over a six-month period. The dark blue line is our GDS model. The light blue line is an aging analyzer reading, quite noisy and definitely not reliable enough to work in closed loop. Lab results are shown in magenta squares. Due to sampling difficulty, lab samples are not normally taken and those few tests were carried out by a special request to help calibrate the inference. These infrequent lab tests show how confident are operation regarding the accuracy of the GDS inference: they do not feel the need to sample this stream anymore and rely almost entirely on GDS calculation. Calibration was influenced by desire to match the lab, and not the noisy analyzer. While we hope to see more lab tests for better calibration, this is the inference presently used for controlling the column.

Existence of tray temperature point in the stripping section permits also a bottom GDS model, predicting slippage of butane into naphtha. Fit of the bottom C4 prediction versus lab and analyzer is shown in figure 5. Again here, analyzer performance is nothing to write home about. Inference quality is decent but it works in open loop only because the objective is to minimize C4 in naphtha, not to control it. Bottom C4 minimization is accomplished by maximizing the reboiler (and reflux) to pressure control constraint.

Unifiner debutanizer description

The unifiner debutanizer is diagrammed in figure 6. As opposed to the FCC debutanizer this column has a furnace reboiler and reboiler heat is controlled to satisfy reboiler outlet temperature. While industry is in general agreement that a tray TC should manipulate reboiler heat duty, furnace reboilers are often equipped with a COT (coil outlet temperature) controller. Tray TC has the advantage of cleaner inferential value, but we can live with reboiler outlet TC. There is a rectifying tray temperature controller on the reflux but we would rather keep it open. With the cut being more or less determined by reboiler COT, influence of reflux on %C5 in LPG is small, and closing the rectifying section TC would not have been successful. Our experience in this regard confirms what other people have found [7], that two temperature controllers could compete at times, driving the column into limit cycling.

Similar to the FCC debutanizer but for different reasons, the LPG rundown valve has been a constraint, and our solution was to open the level, manipulating the LPG flow valve directly while controlling the reflux drum level as a CV in APC. Column pressure is controlled by manipulation of off-gas. However the desire is to minimize off-gas, and hence off-gas flow is a CV, which would be controlled to minimum by increasing pressure or decreasing column heat load. The pressure itself is not steady, which is not a problem for our inferential models.

As an interesting point, the %C5 inference is controlled as an integrator using primarily the reboiler COT.

Unifiner debutanizer inferences

Existence of tray temperatures in the rectifying section makes the inference of C5 in LPG possible, helpful because economics call for minimizing bottom C4 subject to a 1% C5 in LPG constraint. Again here, lab samples are not normally taken but we have requested several tests to help calibrate the inference. Calibration results are shown in figure 7. Figure 8 trends a later 6-month period when the column was under APC, which kept the content of C5 in LPG often up to the 1% limit. Unfortunately there were only two lab tests during the period.

Conclusions

GDS is a simplified distillation model, reducing a multi-component problem into just four components and estimating separation in a section of column without rigorous tray-by-tray calculation. The inferential results are surprisingly accurate and robust. We are able to control C5 in LPG at a target of 1%, benefitting the refinery in a number of ways:

- Increasing alkylation unit feed
- Reducing RVP of light virgin naphtha, making it easier to blend into gasoline. It is also required to keep the integrity of the LVN storage tank.

<u>GCC Literature</u>

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Figure 1. GCC example performance

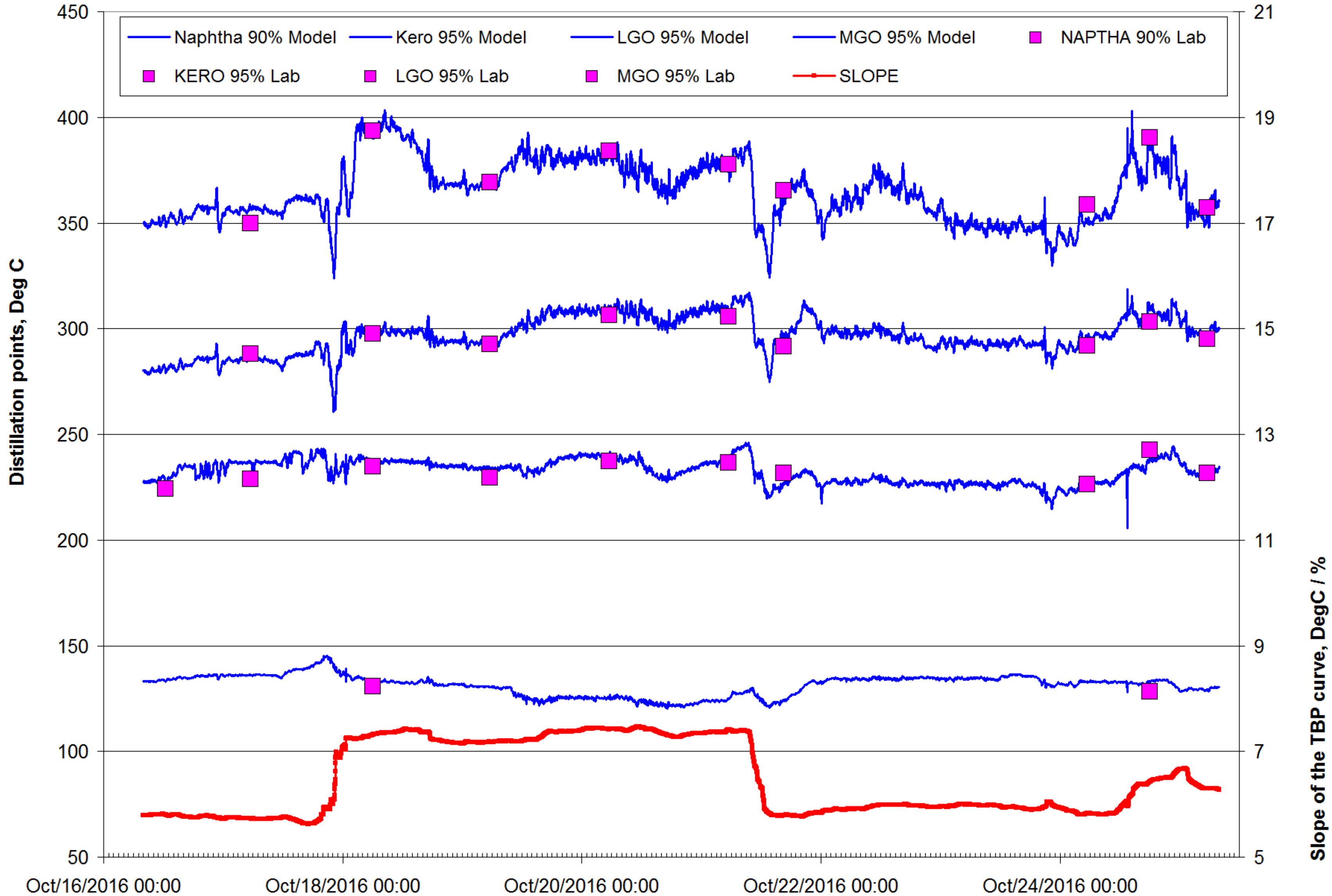

Figure 2. Stripping section GDS input data

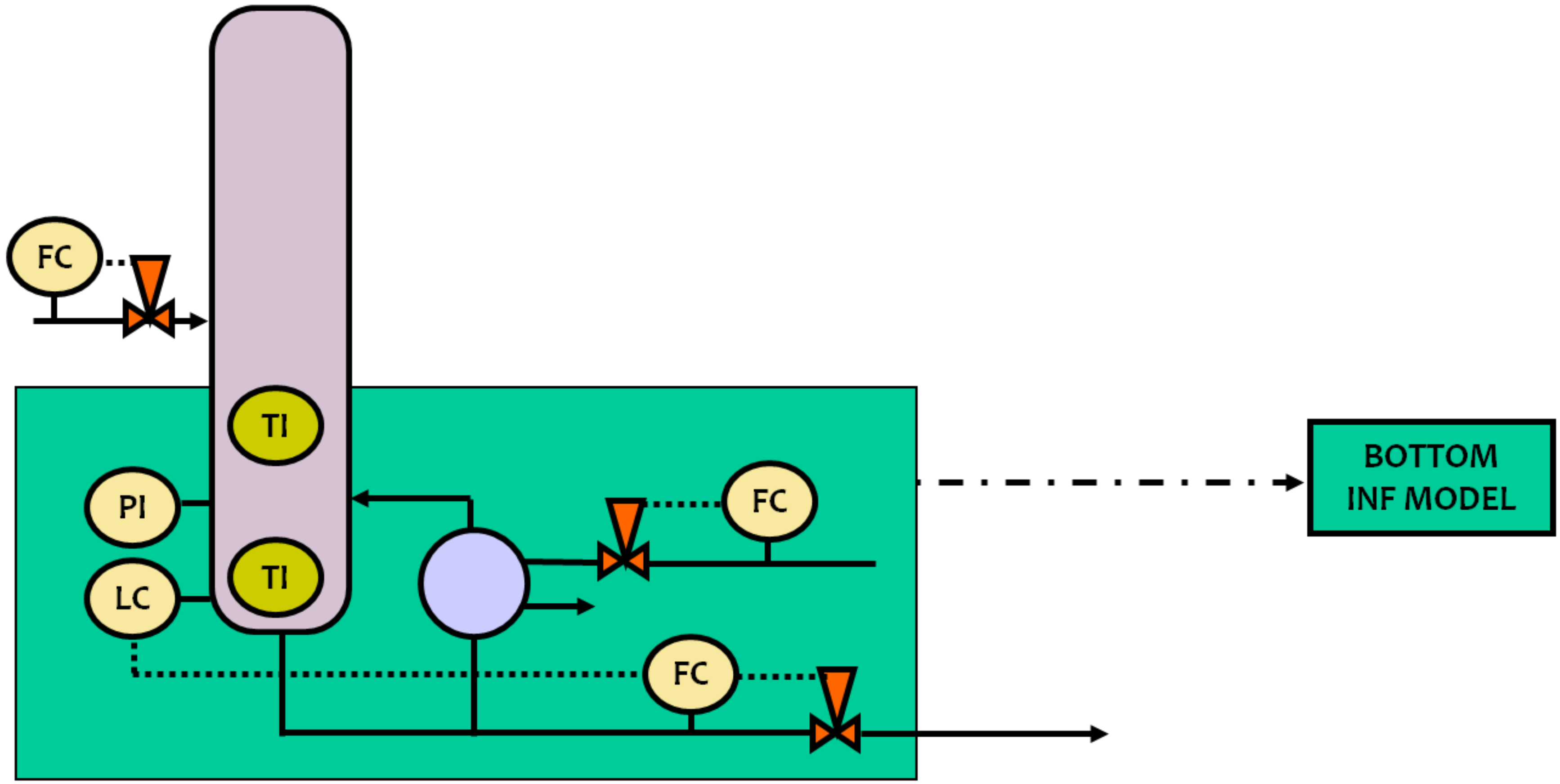

Figure 3. LOR FCC debutanizer configuration

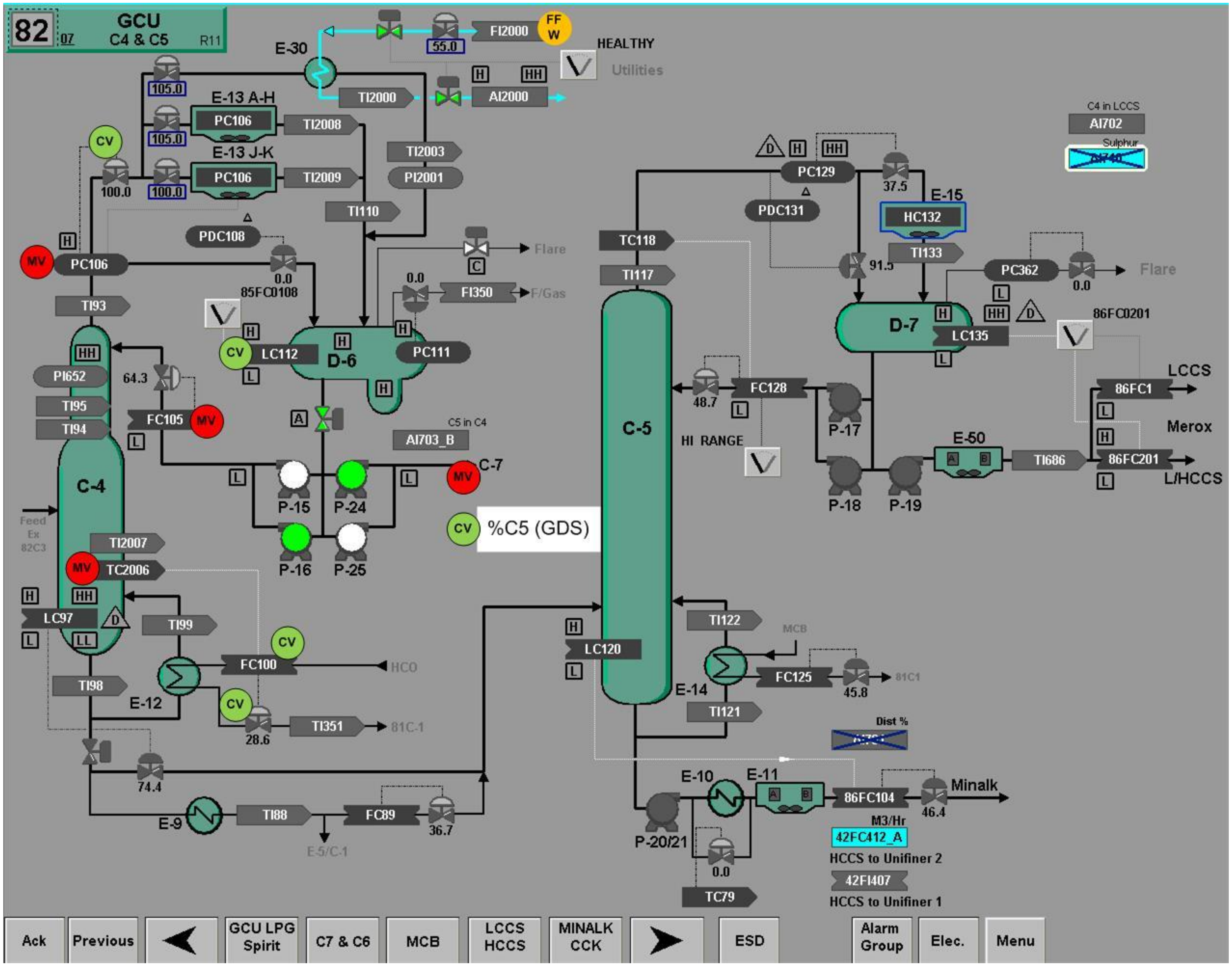

Figure 4. Trend of C5 in FCC LPG

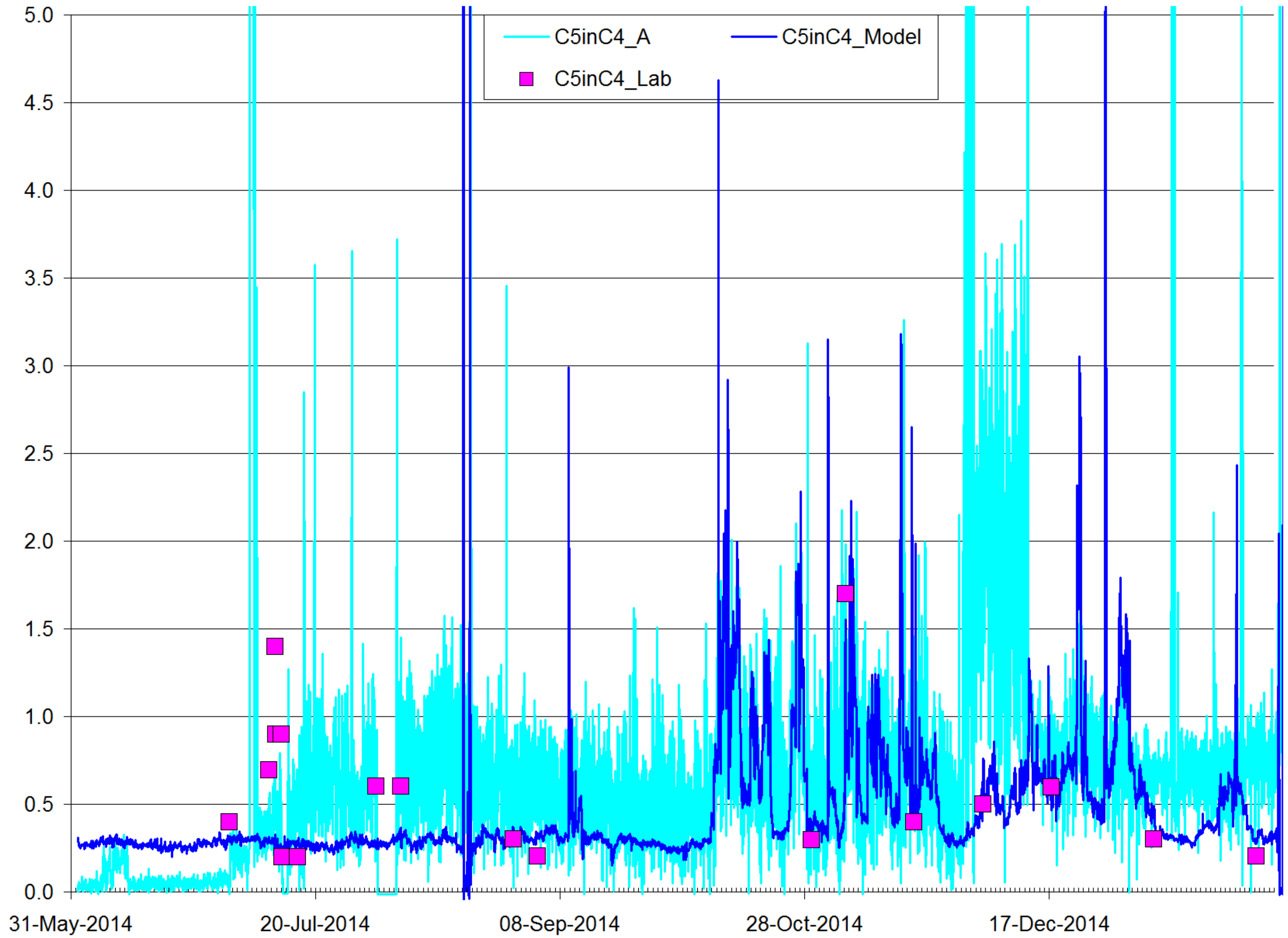

Figure 5. Trend of C4 in FCC light naphtha

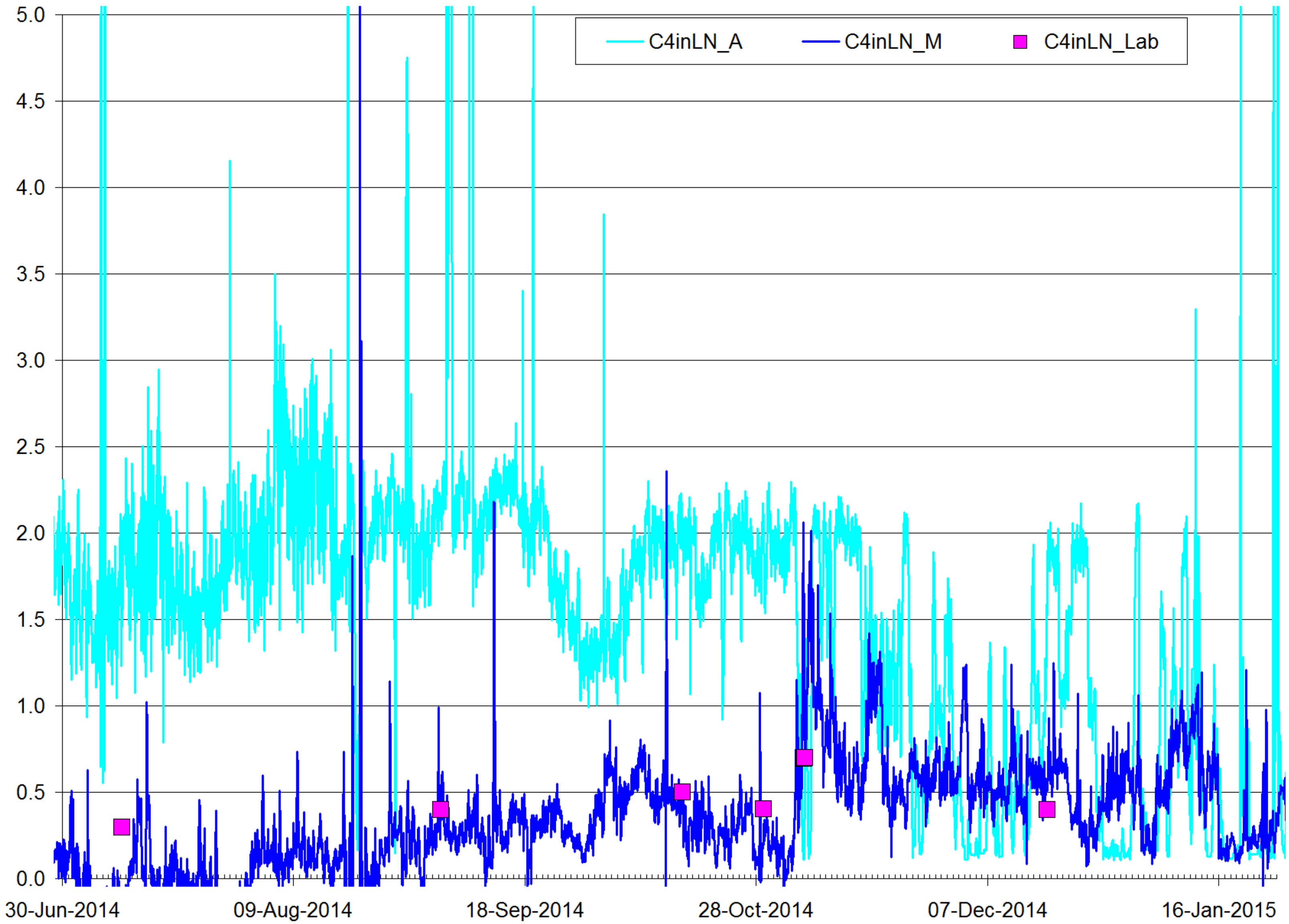

Figure 6. Unifiner debutanizer configuration

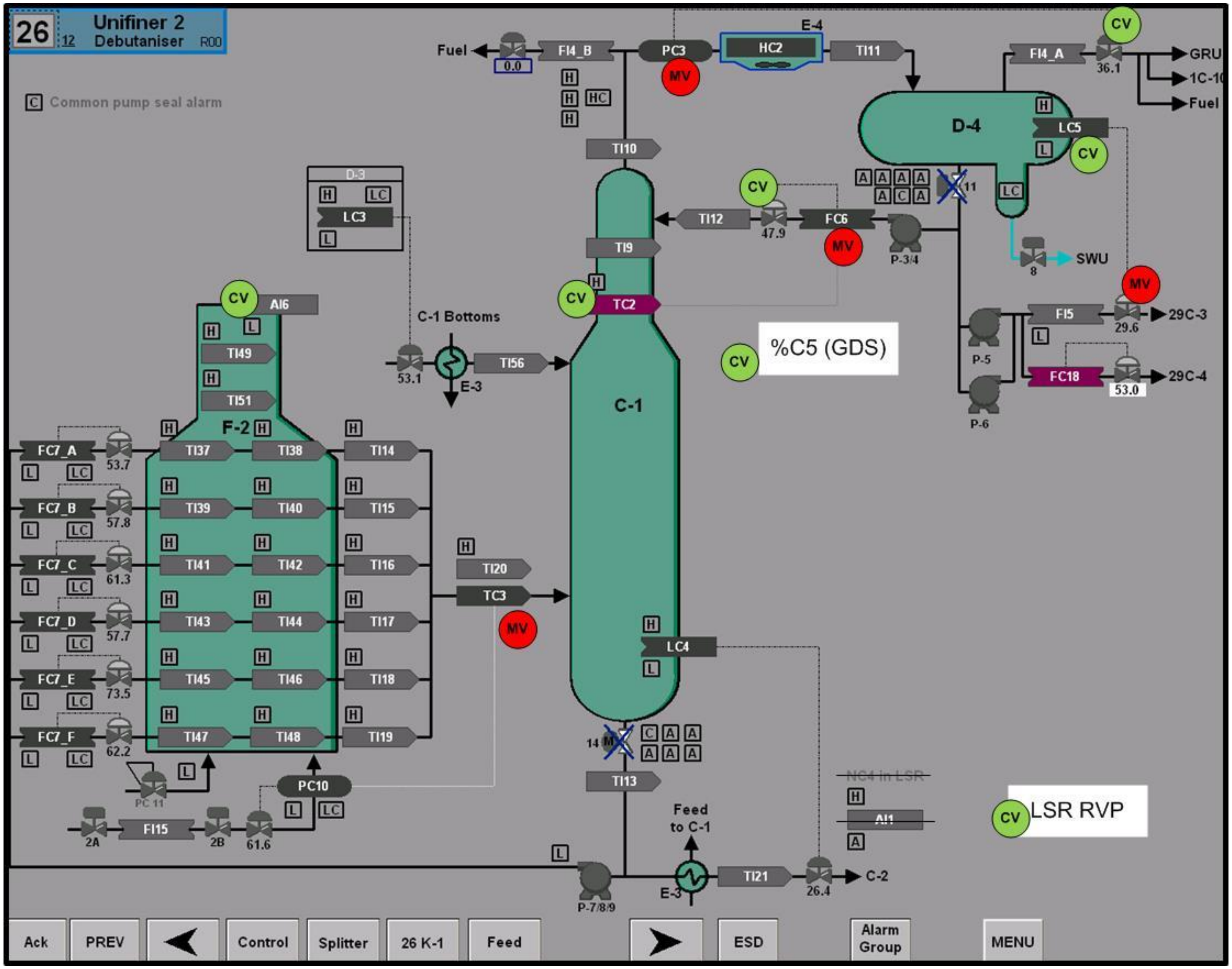

Figure 7. Three month trend of unifiner C5 in LPG

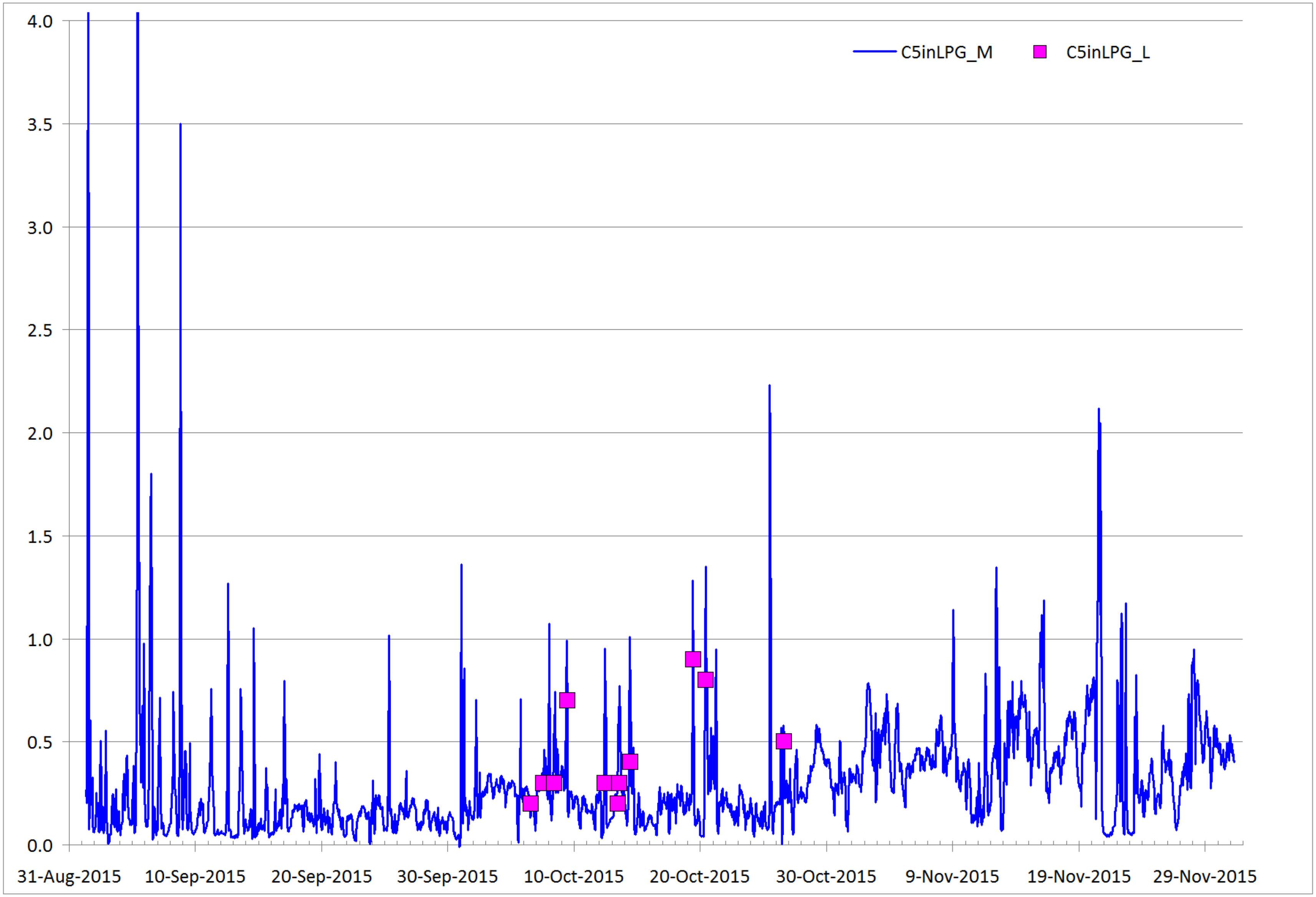

Figure 8. Six-month trend of unifiner C5 in LGP