Lunch and Learn – burn_emis and egr_calc

Documentation – cyflex.com

Burned Gas Composition

Exhaust Gas Recirculation (EGR) Calculations

History (Excuses)

- Single cylinder engines, Turbo Basic.
- ASSET gen_labels
- Carbon Balance Error for portable emissions benches
- PAM calculations – ISO, G1, etc.
- Real-time bsNOx feedback
- Natural Gas – ONGA
- Multi-fuel engines
- Exhaust Gas Recirculation - EGR

burn_emis Specification File

```
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
#
#                                burn_emis_spec
#
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
#
#  This is a specification file for the "burn_emis" task.  For details on using
#  burn_emis, type "use burn_emis" on the command line.  The calculations used
#  in this task are documented here:
#
#  https://cyflex.com/cyflex-manuals/burn-emissions/
#
#  Several different instances of the "burn_emis" task can be running at the
#  same time.  Often one will be setup to perform burned gas composition and
#  emissions calculations in real time to provide feedback and another
#  instance will be synchronized with a fuel reading.
#
#  The @REG_NAME keyword is used to distinguish between instances.  It is
#  considered good practice to select a registered name that reflects
#  whether the instance if real time or fuel reading based.
#
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

@REG_NAME
  burn_fr

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
#
#  The @COMPUTE_EVENT keyword is used to specify the event or timer interval
#  that will be used to trigger the calculation and the event that will
#  be emitted when the calculation is complete.  The calculation done
#  event can be used to "cascade" a series of calculations, most notably
#  those associated with egr.
```

```
#
#  For a real time instance of burn_emis, the event would typically be SLO,
#  MED or FAS.  In newer versions of Cyflex that support phased timer events,
#  a delayed timer event such as MED2 should be used if the inputs to the
#  calculations are being updated at one of the base intervals.  See
#  https://cyflex.com/wp-content/uploads/2018/11/PhasedTimers4.pptx
#  for a description of phased timers.
#
#  For an instance of burn_emis that uses inputs that are averaged over a
#  fuel reading, use the fr_ready event to trigger the calculation.
#
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

@COMPUTE_EVENT
  # compute event             done event name
  fr_ready                    burn_fr_done

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
#
#  The @BURNED_STREAM keyword is used to specify two outputs and one input.
#
#  The burn_emis task will load the calculated burned gas composition into the
#  composition variable specified by the first entry.
#
#  The calculated burned gas mass flow rate will be loaded into the variable
#  specified in the second entry.
#
#  The third entry, the temperature of the burned gas stream, is only important
#  for overall rich combustion.  It can be safely set to a measured temperature
#  such as tur_ot_t or exh_stk_t for overall lean combustion.  For overall
#  rich combustion, an additional equation is required that involves and
#  equilibrium constant that is a function of this specified temperature.
#  ( Consult 40CFR1065 for the appropriate temperature to use. )
#
#  Both the composition and burned gas mass flow variables will be created if
#  they do not already exist.
#
```

```
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

@BURNED_STREAM
  # composition label     mass flow label      burned gas temperature
  burn_gas_frC.           burn_gas_mf_fr       tur_ot_t

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
#
#  The @INPUT_STREAMS keyword is used to provide a list of the composition
#  variables and mass flow rates that define the various input streams.
#  Because the number of input streams is not limited, this list is ended with
#  a "$" as the final entry.
#
#  Typically, there are two streams specified; fuel and combustion air.  For
#  test cells equipped with a balance type fuel scales, fuel rate
#  measurements are only available after the completion of a fuel reading.
#
#  Real-time burned gas composition calculations may be based either on
#  an estimated fuel rate, usually defined as a funtion of an ECM commanded
#  fueling, or based on a measured exhaust gas concentration of either oxygen
#  water vapor or carbon dioxide.
#
#  If a measured exhaust gas concentration is used, the mass flow rate of one
#  of the streams becomes an output and is specified as such by preceding the
#  label name with a ">".  An example is provided below as a commented line.
#
#  The measured exhaust gas concentration that is to be used for this
#  calculation should be specified by preceding the label with a "<" under the
#  @MEASURED_CONCENTRATIONS keyword as described below.
#
#  This feature is not limited to any one stream.  It can be used on one
#  and only one of the input streams in the list.
#
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

@INPUT_STREAMS
  # composition         mass flow
```

```
  # variable label      variable label
#  diesel_certC.         >FR_Fuel_rate
  diesel_certC.         FR_Fuel_rate
  inlet_airC.           FR_air_mf

$

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
#
#  The @MEASURED_CONCENTRATIONS keyword is used to specify the labels for
#  names of the variables that contain the measured or calculated exhaust
#  gas concentrations of CO2, CO, NOx, O2, HC, ammonia, methane and H2O.
#  The identity of the component may be specified using either the old two
#  letter identifiers or the preferred new identifiers.  The old identifiers
#  are:
#        identifier                component
#        C2                        dry CO2
#        CO                        dry CO
#        NX                        dry NOx
#        NW                        wet NOx
#        O2                        dry O2
#        HC                        wet HC
#        WA                        wet H2O
#
#  The new identifiers are:
#        identifier                component
#        CD_CO2                    dry CO2
#        CD_CO                     dry CO
#        CD_NOX                    dry NOx
#        CD_O2                     dry O2
#        CD_METHANE                dry methane
#        CW_HC                     wet HC
#        CW_H2O                    wet H2O
#        CW_CO2                    wet CO2
#        CW_CO                     wet CO
#        CW_NOX                    wet NOx
#        CW_O2                     wet O2
```

```
#        CW_METHANE               wet methane
#        CW_AMMONIA               wet ammonia
#
#  Because the number of measured concentrations is not fixed, this list is
#  ended with a "$" as the final entry.
#
#  Preceding a label with a "<" indicates that the measured concentration is
#  to be used to back-calculate the flow rate indicated with a ">" under the
#  @INPUT_STREAMS keyword above.  Only one label at a time may be used and
#  it must be either CO2, O2 or H2O.  An example is provided below as a
#  commented line.
#
#  The H2O concentration is not often measured, but is included here
#  primarily as an input to be used as a way to calculate the fuel/air
#  ratio that would produce a give water vapor concentration in the exhaust,
#  usually one that would be sufficiently high to cause condensation in
#  an egr cooler at a given temperature.
#
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

@MEASURED_CONCENTRATIONS
  # selected component   concentration label
#  C2                      <exh_cd_co2_mea.AV
  C2                     exh_cd_co2_mea.AV
  CO                     exh_cd_co_mea.AV
  NX                     exh_cd_nox_mea.AV
  O2                     exh_cd_o2_mea.AV
  HC                     exh_cw_hc_mea.AV
#  WA                      exh_cd_h2o_mea.AV

$

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
#
#  The @POWER keyword is used to specify the variable for the brake horsepower
#  reading needed to calculate brake specific emissions based on measured
#  exhaust gas concentrations.
```

```
#
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

@POWER
  # horsepower label
  FR_BHP

# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
#
#  The @EMISSION_RESULTS keyword is used to specify the emissions variable
#  name that will be used to output the results of any emissions calculations.
#  The emissions variable will be created automatically.
#
# %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

@EMISSION_RESULTS
  # emission variable label
  exh_frE.
```

Emissions Variables

EMISSIONS VARIABLES

index	label	composition_label
7	exhE.	exhC. owner= Emission

measured mass flow rate of fuel **(FUEL_MF_MEA)**

This is the sum of the @INPUT_STREAMS mass flow rates which have the stream identifiers: GAS1, GAS2, NATURAL_GAS, GASOLINE, GASOLINE_VAPOR or DIESEL_FUEL. burn_emis will complain if you try to use AIR_FUEL_MIX or AIR_FUEL_MIX_DP

measured mass flow rate of combustion air **(AIR_MF_MEA)**

This is the sum of the @INPUT_STREAMS mass flow rates which have the stream identifiers: COMBUSTION_AIR or COMBUSTION_AIR_DP.

measured mass flow rate of wet exhaust **(EXH_MF_MEA)**

This is the sum of all the @INPUT_STREAMS mass flow rates independent of the stream identifiers.

molar concentration of CO2, dry, measured **(EXH_CD_CO2_MEA)**

molar concentration of O2, dry, measured **(EXH_CD_O2_MEA)**

molar concentration of CO, dry, measured **(EXH_CD_CO_MEA)**

molar concentration of NOX, dry, measured **(EXH_CD_NOX_MEA)**

molar concentration of HC, wet, measured **(EXH_CW_HC_MEA)**

molar concentration of NOX, wet, measured **(EXH_CW_NOX_MEA)**

These are the measured concentrations used for the calculations. NOTE – original list only, investigate to determine what happens if new species are input.

fuel molar mass **(FUEL_MW)**

The molar mass of the combined fuel streams. For details, see equations rsc.9 and rsc.34 in Reactant Stream Composition and Molecular Weight as examples.

mass flow of dry combustion air **(AIR_MF_DRY)**

The mass flow rate of air if all the water vapor is removed.

theoretical molar concentration of CO2 in dry exhaust **(CD_CO2_TH)**

theoretical molar concentration of O2 in dry exhaust **(CD_O2_TH)**

The calculated concentration of equilibrium combustion products in the exhaust on a dry basis. For details, see equations bgc.42 and bgc.43 in Burned Gas Composition.

theoretical dry to wet correction factor **(DRY_TO_WET_TH)**

Correction factor used to convert concentration measurement made on a dry basis to actual 'wet' exhaust concentration. Assumes the sample dryer is 100% effective in removing all water vapor from the sample. For details, see equation ge.1 in Gaseous Emissions.

molar concentration of CO2 in wet exhaust **(CW_CO2_G1)**

molar concentration of CO in wet exhaust **(CW_CO_G1)**

molar concentration of NOX in wet exhaust **(CW_NOX_G1)**

molar concentration of HC in wet exhaust **(CW_HC_G1)**

The measured concentration of combustion products in the exhaust, corrected to a wet basis.

mass flow rate of CO2 from exhaust **(MF_CO2)**

mass flow rate of CO from exhaust **(MF_CO)**

mass flow rate of NOX from exhaust **(MF_NOX)**

mass flow rate of HC from exhaust **(MF_HC)**

Mass flow rate of species in the exhaust gas. For details, see equation ge.3 in Gaseous Emissions.

molar mass of unburned HC in exhaust

(MW_HC)

Molar mass of unburned hydrocarbon per carbon atom. For details, see equations ge.4 and ge.5 in Gaseous Emissions.

carbon balance error **(CBE)**

Carbon into the engine based on the measured fuel rate minus carbon in the exhaust from all measured carbon bearing species divided by carbon in. For details, see Component Balances.

carbon balance error based on CO2 measurement only **(CBE_CO2)**

Carbon into the engine based on the measured fuel rate minus carbon in the exhaust from only CO2 divided by carbon in. For details, see Component Balances.

air-fuel ratio err based on measured dry O2 exhaust conc. **(AFDE_O2)**

air-fuel ratio err based on measured dry CO2 exhaust conc. **(AFDE_CO2)**

The theoretical air to fuel ratio can be calculated based on the measured concentration of O2 or CO2 in the exhaust. This is a comparison between the calculated air to fuel ratio and the measured air to fuel ratio.

brake specific CO2 **(BSCO2_G1)**

brake specific CO **(BSCO_G1)**

brake specific NOX **(BSNOX_G1)**

brake specific HC **(BSHC_G1)**

The mass flow rate of the species in the exhaust divided by the brake horsepower. For details, see equation ge.7 in Gaseous Emissions.

T&H correction for NOX (NOX_COR_G1)

T&H corrected BSNOX (BSNOX_COR_G1)

The 'old' NOx humidity correction factor and the brake specific NOx with the factor applied. It no longer includes a temperature correction. For details, see equations ge.9, ge.10 and ge.11 in Gaseous Emissions.

fuel specific CO2 (FSCO2_G1)

fuel specific CO (FSCO_G1)

fuel specific NOX (FSNOX_G1)

fuel specific HC (FSHC_G1)

Mass of given species in the exhaust gas per mass of fuel consumed. For details, see equation ge.8 in Gaseous Emissions.

fuel-air ratio, wet (FA_WET)

The measured fuel to wet air mass ratio.

dry to wet correction factor (DRY_WET_I1)

molar concentration of CO2, wet, ISO (EXH_CW_CO2_I1)

molar concentration of CO, wet, ISO (EXH_CW_CO_I1)

molar concentration of NOX, wet, ISO (EXH_CW_NOX_I1)

molar concentration of HC, wet, ISO (EXH_CW_HC_I1)

mass flow rate of CO2 from wet exhaust, ISO (EXH_MF_CO2_I1)

mass flow rate of CO from wet exhaust, ISO **(EXH_MF_CO_I1)**

mass flow rate of NOX from wet exhaust, ISO **(EXH_MF_NOX_I1)**

mass flow rate of HC from wet exhaust, ISO **(EXH_MF_HC_I1)**

brake specific CO2, ISO **(BSCO2_I1)**

brake specific CO, ISO **(BSCO_I1)**

brake specific NOX, ISO **(BSNOX_I1)**

brake specific HC, ISO **(BSHC_I1)**

T&H correction for NOX, ISO **(NOX_COR_I1)**

T&H corrected BSNOX, ISO **(BSNOX_COR_I1)**

ISO calculations are no longer being performed. These outputs will no longer be shown in future versions of Cyflex.

pseudo equivalence ratio **(PSEUDO_PHI)**

Weighted ratio of hydrogen and carbon atoms to the number of oxygen atoms. Used to determine whether the combustion process is lean, stoichiometric or rich. For details, see equations bgc.10, bgc.11 and bgc.18 in Burned Gas Composition.

theoretical vs. measured CO2 error **(CO2_ERR)**

theoretical vs. measured O2 error **(O2_ERR)**

A comparison between the measured CO2 and O2 concentrations and the theoretical equilibrium concentrations based on the measured input streams.

Improvements

- Multiple, specialized instances of burn_emis
    - Full 1065 calculations
    - Simplified calculations per ISO, TA Luft, Method 19, etc.
- Moist to wet corrections
- Cummins Standard Air reevaluation.
- Rethink stream identifiers
- Other?