16.2 (a) From Eq. (16.7) in the text, upon introducing the elements of the transfer function model given for the polymer process, we obtain the following expression for the <u>feedforward only</u> controller:

$$u(s) = \underbrace{\left(\frac{11.0s+1}{-550.0}\right)}_{g_{st}} y_d \;-\; \underbrace{\left[\frac{4.5(11.0s+1)}{550(5s+1)(25s+1)}\right]}_{g_{ff}} d(s) \qquad (16.1)$$

The implementation block diagram is shown below in FIG S16.2.

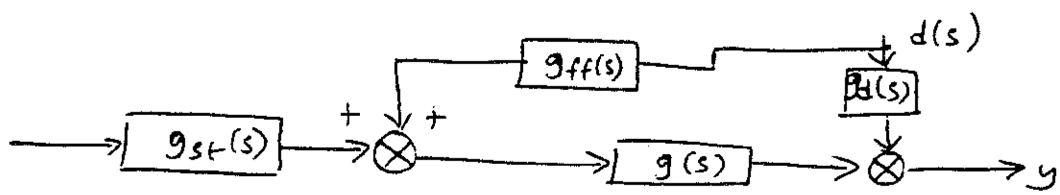

FIG S16.2

The indicated controllers are implementable because there are no predictive elements, neither are there any unstable elements. g_{st} is implementable as a PD controller; g_{ff} as a second order system with a single zero.

(b) The response is shown in FIG S16.3 (with the symbol).

(c) The response is shown in FIG S16.3 (with the symbol +) and the resulting offset is evident. (Note that in practice, however, such an offset of about 20 in the number average molecular weight will not be noticeable.) The offset is clearly a direct result of the model error.

(d) The response is shown in FIG S16.3 (with symbol □)

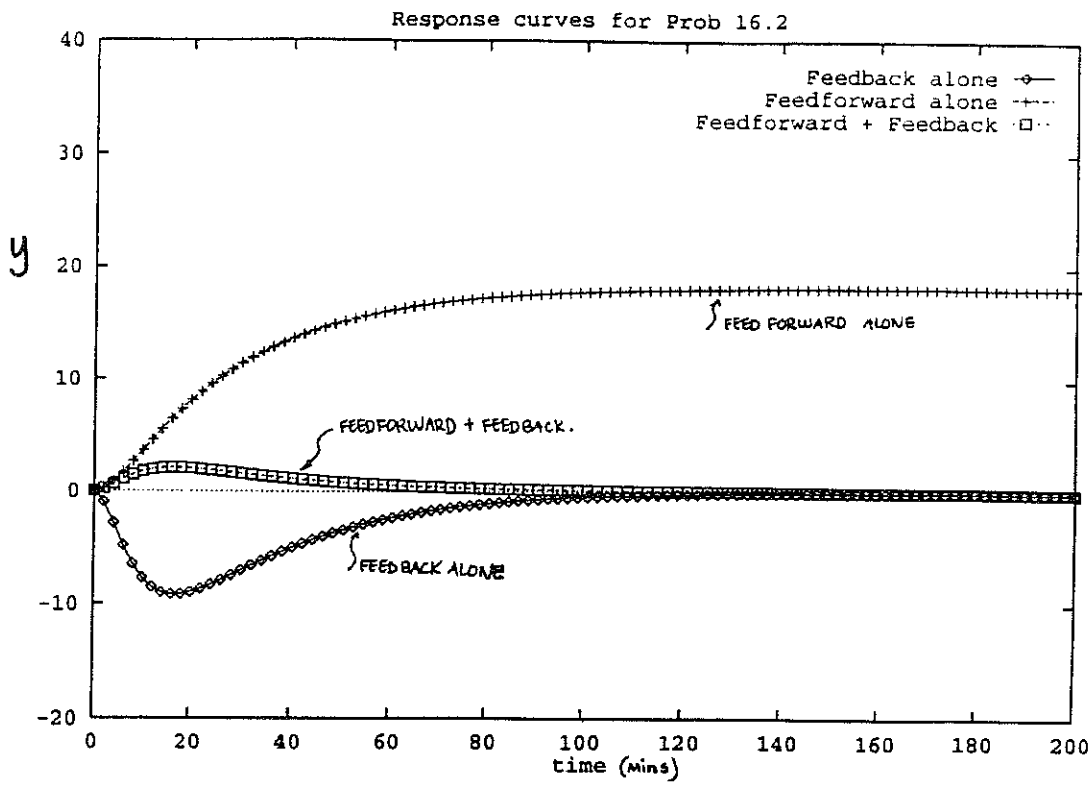

FIG S16.3

As illustrated here, clearly feedforward alone is quite susceptible to the effect of model errors. The amount of offset will depend on the amount of model error.

Feedback alone will leave no offset (if there is integral action) but observe that the process upset lasted for close to 100 minutes: feedback control is unable to correct for upsets until the process is affected.

When the feedforward scheme is augmented with feedback, we see the anticipatory nature of feed-forward cutting down the maximum amount of deviation from set-point; we also see the feedback eliminating the offset. This combination yielded the best response.

And now by comparing Eqn (16.13) with the inequality in (16.10) we observe that the stability range for conventional feedback control is, in this case, almost 3 times narrower than the stability range for the cascade control system.

16.6 (a) The block diagram is shown below in FIG S16.9

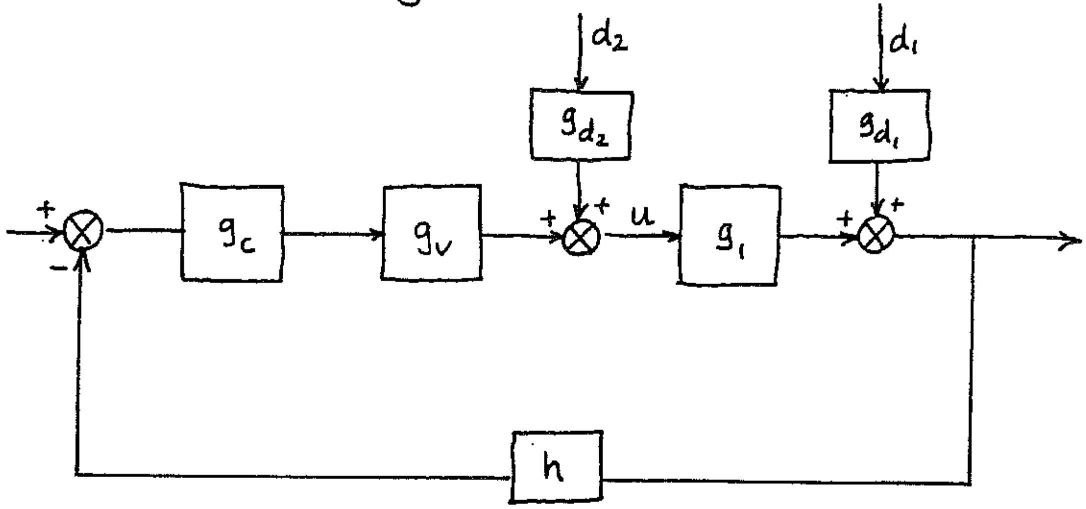

FIG S16.9

The closed loop transfer function equation is:

$$y = \frac{g_1 g_v g_c}{1 + g_1 g_v g_c h} y_d + \frac{g_1 g_{d_2}}{1 + g_1 g_v g_c h} d_2 + \frac{g_{d_1}}{1 + g_1 g_v g_c h} d_1 \qquad (16.14)$$

(b) The characteristic equation:

$$1 + g_1 g_v g_c h = 0$$

under the given circumstances becomes

$$1 + \left(\frac{0.5}{5s+1}\right)\left(\frac{2}{0.5s+1}\right) K_c \left(1 + \frac{1}{0.2s}\right)\left(\frac{1}{0.2s+1}\right) = 0$$

or

$$1 + \frac{K_c\,\cancel{(0.2s+1)}}{(5s+1)(0.5s+1)(0.2s)} \cdot \frac{1}{\cancel{(0.2s+1)}} = 0$$

or

$$0.2s\,(5s+1)(0.5s+1) + K_c = 0$$

$$0.5s^3 + 1.1s^2 + 0.2s + K_c = 0$$

Stability now requires

(i) $K_c > 0$, and

(ii) $a_1 a_2 > a_0 a_3$, in this case

$$1.1 \times 0.2 > 0.5 K_c$$

$$\Rightarrow \boxed{K_c < 0.44} \qquad (16.15)$$

(c) The new controller should be configured to accept pressure measurements and manipulate the steam value opening. The block diagram is shown in FIG S16.10 below.

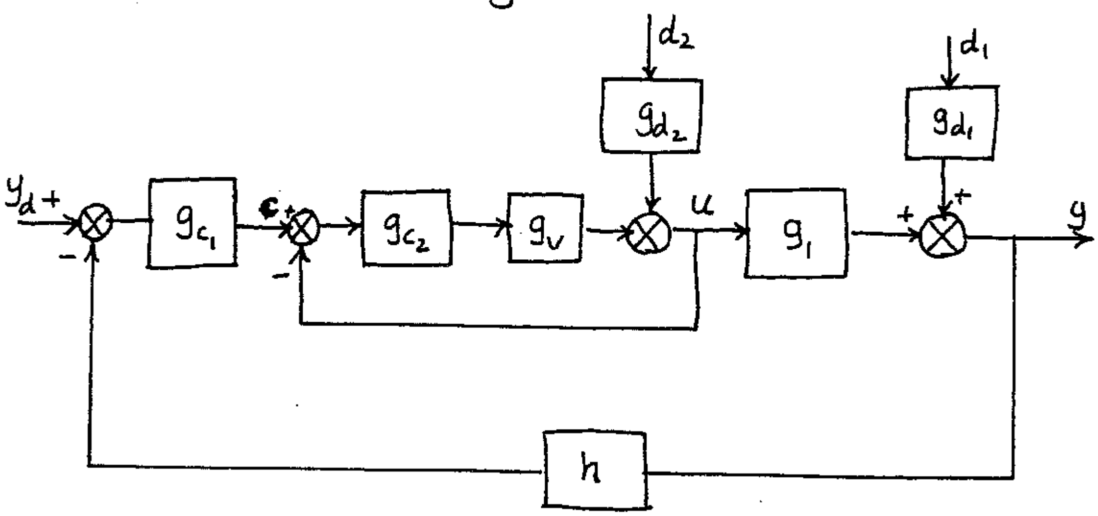

FIG S16.10

Consolidating the inner loop, we obtain

$$u = \underbrace{\left(\frac{g_v K_{c_2}}{1+g_v K_{c_2}}\right)}_{g_1^*} c + \underbrace{\left(\frac{g_{d_2}}{1+g_v K_{c_2}}\right)}_{g_{d_2}^*} d_2 \qquad (16.16)$$

and the overall closed loop characteristic equation becomes

$$1 + g_1 g_1^* g_{c_1} h = 0$$

with g_1^* as indicated in Eq.(16.16) above. This equation rearranges to give

$$1 + g_v K_{c_2} (1 + g_1 g_{c_1} h) = 0$$

Upon introducing the given transfer functions, we obtain

$$1 + \frac{10}{0.5s+1} + \left(\frac{0.5}{5s+1}\right)\left(\frac{10}{0.5s+1}\right) K_c \left(\frac{\cancel{0.2s+1}}{0.2s}\right)\left(\frac{1}{\cancel{0.2s+1}}\right) = 0$$

which simplifies to

$$0.5s^3 + 11.1s^2 + 2.2s + 5K_c = 0$$

And now stability requires

(i) $K_c > 0$

(ii) $11.1 \times 2.2 > 0.5 \times 5K_c$

or $\boxed{K_c < 9.678}$ (16.17)

Comparing Eq.(16.17) with Eq.(16.15) shows how the cascade control loop has enlarged the stability range more than 20 times.